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BACHELOR'S THESIS

Degree in Aerospace Engineering

Study of the Trajectory of a Stratospheric Weather Balloon

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Abstract

Weather scientific balloons allow for very little control over their trajectories. Although there exist systems to influence the burst altitude of the balloons, their horizontal motion is almost solely dictated by the vagrancy of the wind.

The precise forecast of balloon trajectories is thereby a topic of considerable importance to flight operations personnel, since launch/no-launch decisions must be made relying on the likelihood of the balloon landing in some undesirable location. Such concerns are specifically acute in areas with high population densities or prominent areas of restricted airspace, both of which are rather widespread in Madrid and surrounding areas.

This paper aims to accurately present a general overview of stratospheric balloons, covering their functioning, main parameters, types and issues regarding envelopes' elasticity among others.

The mathematical fundamentals of the dynamics of a balloon trajectory are also discussed, as well as the major already existing and self-developed software implementations to this day. Similarly, significant subjects concerning the obtaining of wind data models and the comparison among different predictive models are considered and examined.

Last sections are devoted to regulatory and socioeconomic frameworks, including rough budget estimations and beneficial impacts. Likewise, a futuristic business and entrepreneurial vision of the project will be here presented.

Keywords: trajectory prediction, balloon flight dynamics, wind data source, elastic behaviours, softwares' comparison

LaTeX was used as text editor.

Matlab R2018a was used as programming tool.

Images were created with Microsoft PowerPoint 2016.

All images are original or searched in Google
under “Free to use, share or modify” filter.

Acknowledgements

Looking ahead to 2014, when University started, nobody could have ever told me how intense those still upcoming four years would have been. Nowadays I can only feel thankful to mostly all of my classmates because I really believe that pretty much all of them has taught me at least something. Besides that, I would also like to truly thank my lifelong friends - Jorge Juan Piris, Natalia Torrado and Alba Ropero.

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Looking to the future, I just want to feel at least a quarter amount of gratefulness and happiness as I experience today. Once again, a thousand thanks.

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Nomenclature

$\mathbf{x}$	vector
s	scalar
N_2	Molecular nitrogen
O_2	Molecular oxygen
Ar	Argon
CO_2	Carbon dioxide
O_3	Ozone
p	Pressure $[Pa]$
V	Volume $[m^3]$
n	Number of moles $[mol]$
R	Ideal gas constant $[J/K \cdot mol]$
T	Temperature $[K]$
ρ	Density $[kg/m^3]$
g	Gravity $[m/s^2]$
dp	Differential pressure [-]
dh	Differential height [-]
α	Gradient slope $[K/m]$
θ	Non dimensional variable [-]
δ	Non dimensional variable [-]
σ	Non dimensional variable [-]
m	mass [kg]
a	acceleration $[m/s^2]$
F_b	Buoyant force [N]
F_g	Gravitational force [N]
F_d	Drag force [N]
v_{rel}	Relative velocity [m/s]
C_D	Drag coefficient [-]
A	Area $[m^2]$
F	Force [N]
p_{out}	External pressure [Pa]
p_{in}	Internal pressure [Pa]
$\mathrm{p}\,(\xi)$	Inflation or membrane pressure [Pa]
ξ	Stretch [m]
r	Deformed radius [m]
r_0	Non-deformed initial radius [m]
v_z	Ascent velocity [m/s]
m_{lifted}	Lifted mass [kg]
t_0	Undistorted thickness [m]
W	Strain energy density function $[N/m^2]$
I	Invariant [-]
n	Positive constant
c_1	Positive constant
c_2	Positive constant
μ	Shear modulus [Pa]
γ	Dimensionless parameter [-]
J_m	Gent parameter [-]
h	Height [m]
z	Altitude [m]
λ	Latitude [°]
φ	Longitude [°]

1 Introduction

1.1 Overall context - Statement of the problem

On September 19th, the world came to live the first passenger balloon flight in the entire history. This balloon which carried a sheep, a duck and a rooster was built by the Montgolfier brothers in Annonay, France in 1783. [1]. This worldwide breathtaking news was the first that brought human beings closer to their greatest dream of flying.

A balloon is a pretty simple flying machine. It is conceptually an enveloping fabric filled with a gas that is lighter than the surrounding atmosphere, commonly known as air. That means that as the entire balloon is less dense than its outside ambient, it rises. At this stage, it is worth mentioning that a balloon has no propulsion system although it may control itself through air by making the balloon rise or sink in altitude thanks to favorable wind directions. The kind of vehicle that has a motor to propel itself is known as airship. [2].

Many balloons usually include a basket (also called gondola or capsule) attached underneath the main envelope for carrying payload of people or equipment, such as cameras, sensors, telescopes, flight-control mechanisms or radio machines among others. It is evident that the more cubic meters of gas a balloon can hold, the more weight and payload can lift. [2].

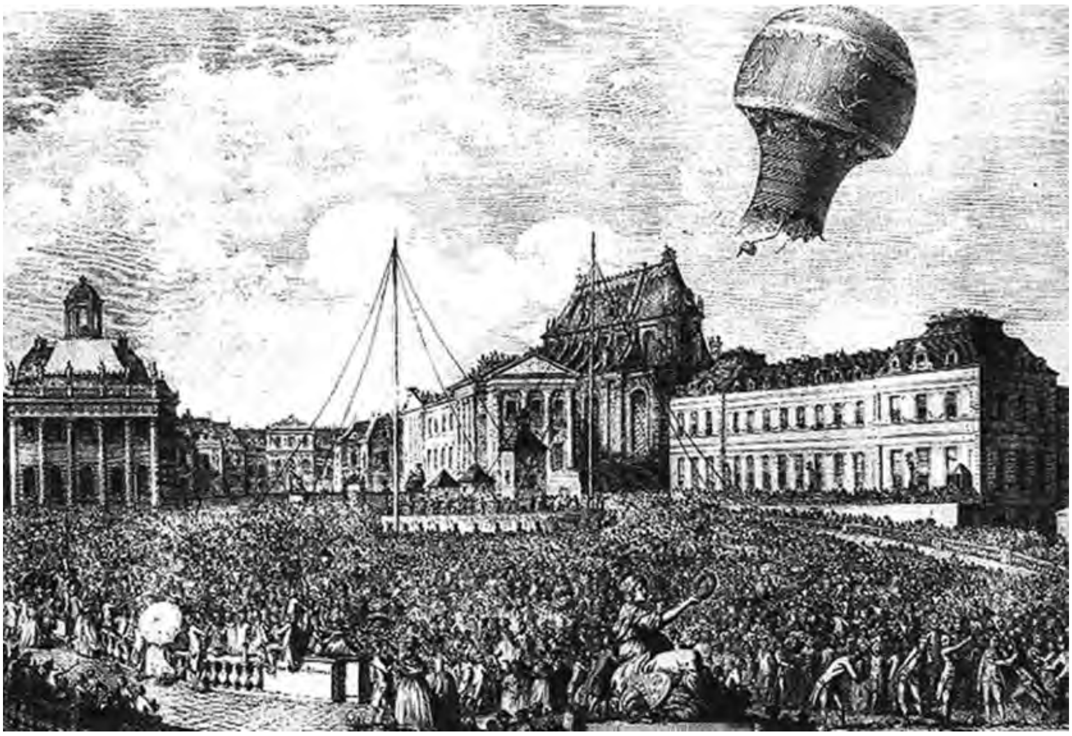

Figure 1: The first balloon flight with passengers [1]

Inside this way of transportation, there exist mainly two different kinds of balloons that are described just below.

Aerostatic balloons

Alan Eustace, Google's Vice-President, holds the altitude record of this balloon category reaching 41 kilometres above sea level. [3]. Following, three sub-types are principally distinguished:

- **Hot-air type**, also known as **Montgolfière**: Meant to follow the aforementioned lighter-that-air concept by means of heating the air inside an opened balloon envelope (not sealed at the bottom as the same pressure than surrounding air is desired). In most cases, it is performed via an open flame caused by burning liquid propane. Due to the "Ideal Gas Law", the heated inside air makes it rise since the hotter air has a lower density than the colder outside air. Normally filled of hot air and used for recreational, competitive and touristic purposes. [4].

  This balloon type has not only succeeded performing the first human-carrying flight, but also conducting the first untethered manned flight by Pilâtre de Rozier and d'Arlandes on November 21st, 1783 in Paris, France. [2].

Figure 2: Hot-air type or Montgolfière [5]

- **Gas type**, commonly named as **Charlière**: Manufactured of rigid structures and capable of flying higher and faster that **hot-air type**. [6]. Usually full of hydrogen or helium and equipped with sand-filled ballast sacks. This envelope has to be sealed at the bottom, but valves should be also installed to open it if necessary.

- **Rozière**: Sort of hybrid balloon that has two separated chambers, one for a non-heated lifting gas (such as hydrogen or helium) and another for a heated lifting gas. Its creator was Pilâtre de Rozier. This type of balloon is only used for occasional long-distance record flights, such as circumnavigations. [4].

Figure 3: Gas type or Charlière [7]

Figure 4: Rozière [8]

Stratospheric balloons

Designed to reach stratospheric altitudes (from 18 to 55 kilometres approximately). It could be said that these balloons arrive where aircraft do not, although under no circumstances may they reach the space or altitudes close to it. This type of balloon's altitude record is 52 kilometres above sea level. Their functioning relies on "Archimedes' principle, the physical law of buoyancy", which is principally based on a vertical thrust force, named buoyancy, that exists when the balloon is submerged on a fluid, the air in this case. [9]. However, this will be later explained in detail in Section 2.1.3. There exist three distinct kinds of balloons inside this category:

- **Opened type**: Characterized by letting the inside gas escape, which makes pressure differences between the inside and the outside be null. This is done in order to maintain a constant volume until an equilibrium height is reached and the balloon remains, from that point on, floating. By maintaining the volume at descending pressures, the generated thrust keeps decreasing until the rise stops. At this point, that thrust is said to be equal to the weight of the rest of the components of the balloon. [9].

Figure 5: Opened type [10]

- **Closed super-pressure type**: Marked by not letting the inside gas escape, which makes pressure differences between the inside and the outside increase as the balloon ascends. That makes it explode falling down back to the surface of the Earth. This is done in order to maintain a constant volume and consequently, constant weight. As air pressure in which it floats decreases, thrust experiences a decrease as the weight of the displaced air is lower. Like **opened type**, once an equilibrium height in which its thrust equals its weight is achieved, the balloon is no longer able to withstand such big existing pressure differences without exploding. [9].

- **Closed variable-volume type**: Defined by a constant volume increase as the balloon rises, which makes pressure differences between the inside and the outside be practically zero. This is accomplished thanks to the use of elastic materials in its manufacturing. This way makes the balloon able to stretch and allow equal inside and outside pressures. Because the volume increase is proportional to the pressure decrease, the thrust experienced by the balloon remains constant until the balloon is unable to stretch further. At that point, it becomes a **closed super-pressure type** or it directly explodes letting the gas escape and rapidly initiating the descent. [9].

Figure 6: Closed super-pressure type [11]

Figure 7: Closed variable-volume type [12]

Notwithstanding that society has always dreamt so long about having the opportunity of flying, when fatalities occur, emotions easily appeal by letting issues regarding security grow among all people. That is the reason why developing a software able to predict the trajectory of a **stratospheric closed variable-volume balloon** will not only lessen humankind concerns apart (as pretty exact positions could be obtained), but also a fundamental step forwards on this cutting-edge technological era will be taken.

1.2 State of the art

Stratospheric balloons are also known under the names of "High-altitude balloons" and "Weather Balloons". These balloons have mainly two well-defined tasks:

- To determine upper-level winds and the height of cloud layers by collecting radar or satellite-based data, when balloons do not carry any instrument pack.
- To act either as a transponder when remaining at constant altitudes for long periods of time or as a experiment-performer in similar conditions to the spatial ones in terms of pressure, temperature and radiation, provided that balloons carry instruments.

The first stratospheric launch was carried out by the US Army Air Forces from 1947 until early 1949. "Mogul Project" was the name given to this first top secret project that involved sensitive microphones to detect long-distance sound waves generated by Soviet atomic bomb tests. [13]. However, nowadays there is not as much freedom as before to launch balloons. Issues regarding safety regulations, such as dangerous, prohibited and restricted areas will be discussed in the following pages of Section 4.

Looking to the present, there already exist public software tools that helped developing a home-made implementation model for trajectory predictions. These easy-to-use web-pages are worth mentioning hereunder.

HABHUB - High Altitude Balloon Hub

Habhub is an online high-altitude ballooning web-page in which a bunch of tools are based at. "Balloon tracker", "Burst altitude calculator" or "Landing predictor" are some of their applications, just to mention a few. [14]. Last two mentioned are written by the CUSF - Cambridge University Spaceflight.

⇒ The "Balloon tracker" displays past and present trackings all over the world that are monitored either per radio, per satellite-based Global Positioning System (GPS) messaging or per cellular data systems. [14].

⇒ The "Burst altitude calculator" is implemented to know how much gas is needed to be inside a high altitude balloon to achieve a desired ascent rate. This computing device needs some inputs to properly run, such as payload, parachute and balloon masses. [14].

⇒ The "Landing predictor" tool foretells not only landing locations of latex sounding balloons but also their flight paths using the wind data from the NOAA GFS models. [14]. To be widely covered in Section 2.4.1. As mentioned above, some inputs are here also required (See Fig.8):

- Position coordinates (latitude and longitude) of the launch site
- Launch and burst altitudes [m]
- Ascent and descent rates [m/s]
- Launch date and time (UTC - Universal Time Coordinated)

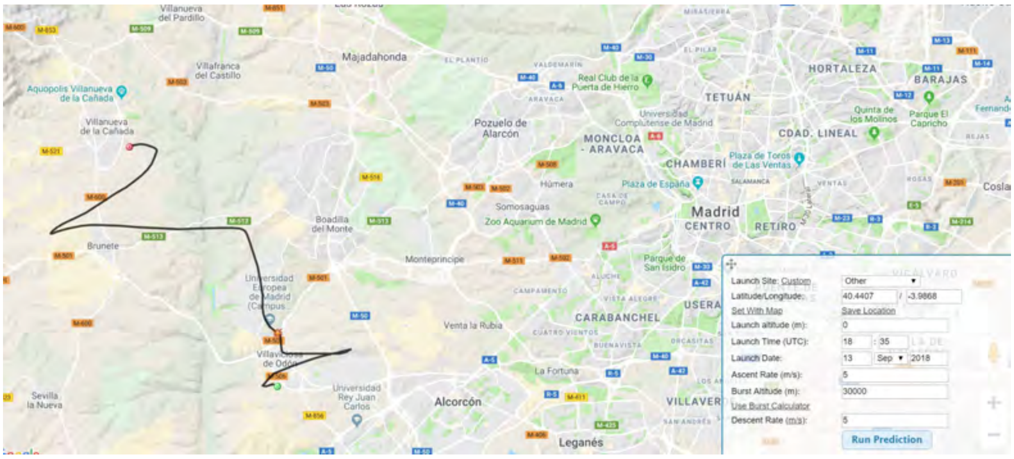

Figure 8: HABHUB Predictor - Villanueva de la Cañada [14]

Fig. 8 shows the evolution of a HAB's trajectory on September 14th 2018 at 18:35. The chosen place for the release is Villanueva de la Cañada, which has around 650 m of elevation above mean sea level - AMSL.

The most important handicap faced within this server is that average climbing and descending speeds are set to be constant for the sake of simplicity. The fact of ignoring and not taking into account ascent and descent rates of balloons may differ results from an exact trajectory prediction model.

ASTRA High Altitude Balloon Flight Planner

ASTRA - Atmospheric Science Through Robotic Aircraft - is a more complex and therefore, more complete software programmed by Niccolò Zapponi. This ground-breaking initiative for its time took place in the University of Southampton and its web-page demands pretty much information regarding balloon parameters as of today. [15]. Listed below:

- Flight information:
  - Launch date and local time
  - Gas type: helium or hydrogen
  - Balloon model: covering all possible weights among Totex and Hwoyee manufacturers

- Parachute model: covering all possible diameters among Rocketman, Spherachute and Totex manufacturers. No parachute option available
- Payload weight [kg]
- Nozzle lift [kg] = actual lift force. Calculated by doing "total or also-called gross lift" minus "weight of the balloon"
- Train equivalent sphere diameter [m]

- Launch site

- Weather data:
  - "Online forecast" (based in NOAA wind data source) or "load sounding"

- Simulation settings:
  - Number of simulation runs
  - "Standard" or "floating" flight type

Next Fig. 9 displays the same balloon, launched with ASTRA at the same date, time and position so that readers can appreciate differences among predictors.

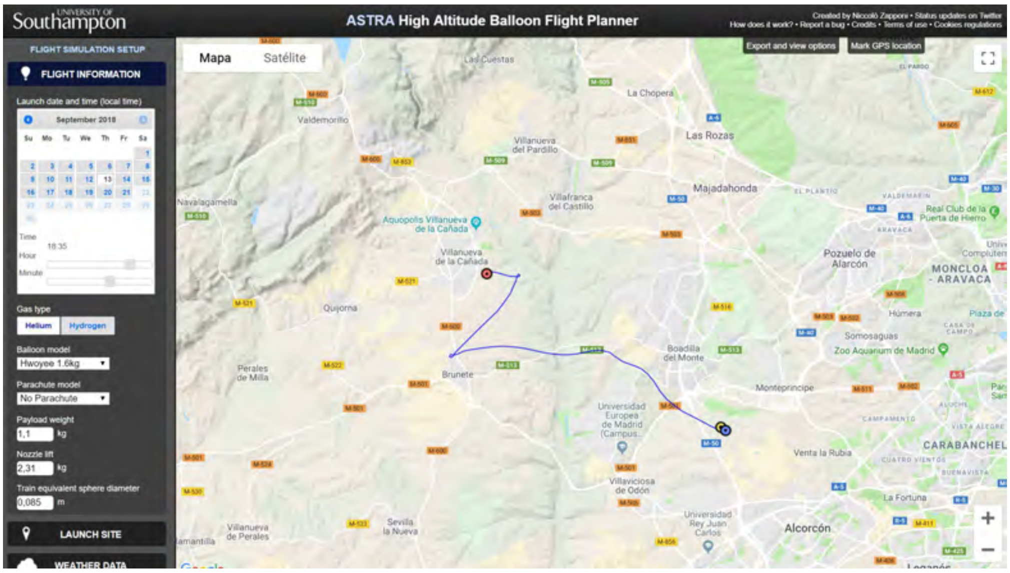

Figure 9: ASTRA Predictor - Villanueva de la Cañada [15]

Taking all these parameters into consideration, Niccolò Zapponi obtained the equations of motion of the balloon by means of LSODE, the "Livermore Solver for initial value problems in Ordinary Differential Equation systems". [16]. Moreover, this researcher pointed out that incomplete interpretations regarding the drag opposing the rise of balloons in the free atmosphere were said to be the main reason of today's inaccuracies in flight-path forecasts. Therefore, a correctly simulation needed to be carried out by proposing a stochastic drag model based on empirical data derived from thousands of radiosonde flights - the Monte Carlo method. The achieved software of simulated trajectories is now re-known to be an excellent and much more complicated flight planning tool. [17].

1.3 Scope of the project

The final objective of this project lies in launching a real stratospheric helium-filled balloon from the surroundings of Madrid up to a height of 34 kilometres. The constant motorization of its trajectory with instruments and its subsequent collection are involved inside the goals of this work.

The selected balloon to be delivered is the **stratospheric closed variable-volume type**, which is designed to be manufactured from elastic materials, such as latex or rubber. And as previously stated, as this kind of balloons gains altitude, an expansion of their envelopes progressively occur.

This project spreads to a great extent as many different departments inside the University are entailed to succeed in distinct disciplines. Some of the experiments that are committed to be fulfilled the release day of the balloon are about measuring suspended particles in the atmosphere, discharging plasma at high altitudes to see its behaviour, studying how the solar radiation varies with altitude or quantifying the friction the balloon perceives in an alleged case of Free Fall .

The main focus of this thesis is to implement a precise and dependable software capable of predicting the trajectory of a high altitude balloon just by considering a given launch location (latitude, longitude) and altitude. It is key to clarify that this self-developed flight path forecaster does not foretell anything related to the fall of the balloon. Consequently, it does not take neither its maximum height or burst radius nor the elastic limit of the envelope into consideration.

In order to accomplish this purpose, previous tasks had to be studied including:

✓ Inquiry into weather balloon generalities and principles of functioning
✓ Distribution of atmospheric layers and wind data model research
✓ Study of elastic effects in different models
✓ Analysis of the legal and socioeconomic environments
✓ Creation of a MATLAB code to run this self-developed predictor

The scheduling of these objectives can be observed in Appendix C, where specific remarks and detailed comments are arranged in a time-line.

Additionally, it must be highlighted that the comparison of the collected data from the release of the real balloon with the results coming out from the self-developed trajectory predictor falls outside of the scope of this thesis. This is because the balloon is programmed and expected to take-off in October this year. Hence, by the time this thesis is presented, real data is still unavailable. Even so, this final examination is left to be analyzed in a near future as a great amount of people is immersed within the project.

2 Methodology

2.1 Preceding generals

2.1.1 Atmospheric layers - ISA model

An atmosphere is defined to be a layer or set of layers of gases that surround a celestial body. These gases are normally attracted by that body's gravity and those fluids are retained in this gravity field if it is high enough or if it is subjected to low temperatures. All planets that are part of the Milky Way have their own atmosphere. [18]

Regarding Earth's atmosphere, approximately a 95% of the total amount of gases appear in the first 30 kilometers above mean sea level. [18]. The composition of the atmospheric air follows upcoming proportions:

- 78% of N_2, an inert gas that rarely reacts to other substances
- 21% of O_2, a very reactive gas that is necessary to ensure living beings' life
- 0.9% of Ar, a noble gas that does not react to other substances
- 0.03% of CO_2, a gas that helps to retain most of the heat coming from terrestrial and atmospheric radiation (main cause of greenhouse effect)
- 0.07% of other gases, such as O_3, water vapour or solid and liquid particles in suspension

These layers of gases make life on Earth possible as this atmosphere absorbs the ultraviolet solar radiation with the ozone layer, acts as a protective shield against meteors and reduces the temperature differences between the days and nights. [19].

As it can be appreciated in Fig. 10, layers of Earth's atmosphere are called 'Troposphere', 'Stratosphere', 'Mesosphere', 'Thermosphere' and 'Exosphere'. [19].

Figure 10: Layers of the Earth's atmosphere [20]

On a slightly different note, the International Standard Atmosphere - ISA - is a theoretical vertical distribution of temperature, pressure and density along all terrestrial layers. [21]. This ISA model is based on the next assumptions:

- The air is dry and a perfect gas:

$$p\,V = n\,R\,T, \tag{1}$$

where the universal or ideal gas constant R = 8.3144598 $\frac{J}{Kmol}$

- The standard conditions, which are those measured at sea level, are:

T_0 [K]	p_0 [Pa]	ρ [$^{kg}/_{m^3}$]
288.15	101325	1.225

Table 3: Standard sea level temperature, pressure and density

- Acceleration due to gravity is constant, using geopotential altitude:
g = g_0 = 9.80665 $\frac{kg}{s^2}$

- The hydro-static equilibrium or balance is fulfilled:

$$dp = -\rho g dh \tag{2}$$

- Regarding temperature profiles, two remarks must be pointed out:
  - In the troposphere, temperature decreases linearly with altitude up to 216.65 K. Hence, a gradient slope of α = - 6.5 $\cdot$ 10^{-3} $^{K}/_{m}$ is found in this layer.
  - In the stratosphere, temperature remains constant.

Applying all previous hypothesis, the following expressions are obtained for the non-dimensional variables θ, δ and σ, with altitude, z in metres:

Troposphere (z < 11000 m)

$$\theta = \frac{T}{T_0} = 1 - \frac{\alpha}{T_0} z = 1 - 2.25569 \cdot 10^{-5}\, z \tag{3}$$

$$\delta = \frac{p}{p_0} = \theta^{\,\frac{-g}{\alpha R}} = \theta^{\,5.2561} \tag{4}$$

$$\sigma = \frac{\rho}{\rho_0} = \theta^{\,\frac{-g}{\alpha R}-1} = \theta^{\,4.2561} \tag{5}$$

Tropopause - tpp (z = 11000 m)

θ_{tpp}	δ_{tpp}	σ_{tpp}
0.75187	0.22336	0.29707

Table 4: Tropopause non-dimensional variables

Stratosphere (z > 11000 m)

$$\theta = \theta_{tpp} = 0.75187 \tag{6}$$

$$\delta = \delta_{tpp} \cdot \exp\left(\frac{g\,(z-11000)}{RT_{tpp}}\right) = 0.22336 \exp\left(-1.57688 \cdot 10^{-4}(z-11000)\right) \tag{7}$$

$$\sigma = \frac{\delta}{\theta_{tpp}} = 1.33001\,\delta \tag{8}$$

Note that as this thesis is about weather balloons, only non-dimensional variables' equations of the layers below the stratosphere were covered even though all of them have their own expressions. [21]. The three aforementioned behaviours can be observed in Fig. 11 graphically.

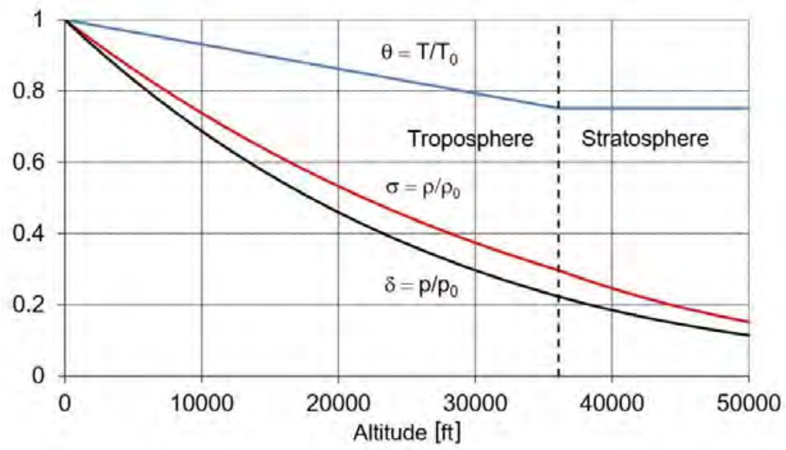

Figure 11: ISA non-dimensional variables of the lower layers [21]

Besides, ISA model is based on average annual conditions at latitude 45° N and although the experiment is going to be performed in a latitude really close to that one, it is frequently necessary to make some variations to approach the model as close as possible to real conditions. This is especially done for variations of temperature at a given altitude. The atmospheric model is generally adjusted in the following way: [21]

- The relationship 'altitude-pressure' is maintained under all circumstances. By definition, this relationship estimates the pressure that the balloon would produce in the standard atmosphere at a certain altitude. And that value would exactly coincide with the pressure the balloon would measure on-board. Mathematically, it would be computed by solving for h in Eqs. 3 and 4 for a tropospheric position or Eqs. 6 and 7 for a stratospheric location.
- The variation of temperature ΔT (°C) is a shift as regards ISA model. There exist hotter and colder days which are represented as ISA -20, ISA +10.
- The density is calculated with the perfect gas law - See Eq. 1. Realize that in a colder day, the balloon will be flying lower than the predetermined pressure-altitude given by ISA model as its density would be higher than the standard one. In a hotter day, completely the opposite would occur.

2.1.2 Balloon and payload data - Helium gas properties

Technical specifications of the chosen meteorological balloon and payload, such as their masses or balloon's released and bursting radii are all covered in Appendix A.

It must be highlighted that the selected balloon's envelope is of 'natural rubber latex' and that the total mass is the sum of the balloon and payload masses.

Regarding gas characteristics, elastic limits depend on whether the balloon is fitted or not with the appropriate amount of gas needed. If the balloon is over-filled, envelope's material will break before reaching burst altitude. On the contrary, if the balloon is under-filled, there will not be enough lifting force to buoy the balloon up as needed to get desired altitude. The required initial mass of helium needed in the release point is calculated in the following manner:

$$m_{He\,0} = \rho_{He}(h=0) \cdot V_{balloon\,0} \tag{9}$$

Observe that the density of the helium decreases as the balloon raises. This is because balloon's volume expands, apart from the altitude increasing. However and although the initial amount of helium inside the balloon is of crucial importance to ensure enough buoyancy, measurement methods are still today very far ahead from getting exact measures. From experience, inaccuracies up to 1 % or 2% of error are accepted in comparison with the real initial referential amount of helium mass. [22].

2.1.3 Archimedes' principle, the physical law of buoyancy

The ancient Greek mathematician and inventor Archimedes is who gives the name to this principle. This physical law states:

"Any object, completely or partially immersed in a fluid, is lifted up by a buoyant force that is equal to the weight of the fluid displaced by that object".

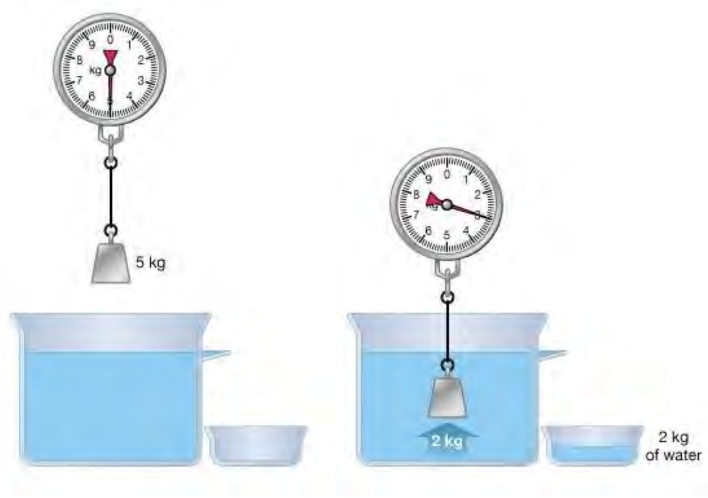

Figure 12: Archimedes' principle [23]

The buoyant force, which always opposes gravity, is however caused by gravity. Fluid pressure increases with depth due to the weight of the fluid above making differences in pressure between top and bottom surfaces of the object appear. [23]. This increasing pressure applies a force on the submerged object which is called buoyancy, $\mathbf{F_b}$:

$$\mathbf{F_b}(z) = V(z)\,\rho_{air}(z)\,g\,\mathbf{z} \tag{10}$$

Nevertheless, the real effective force acting on a balloon resides in the difference in densities between the external fluid (air) and the injected gas (helium).

In addition, Archimedes' Principle clarifies why some objects float and others sink:

⇒ An object will float when the weight of the displaced fluid equals the weight of the object. In other words, an object that is less dense than the fluid in which it is immersed will stay afloat. This is the case of a block of wood that is released beneath the surface of water or a helium-filled balloon that is let loose in air. [23].

⇒ Otherwise, an object will completely or partially sink when the weight of the displaced fluid is less than the weight of the object. [23].

2.2 Flight Dynamics

The aim of next section is to present and discuss the forces on in-flight stratospheric balloons and to derive their equations of motion.

Furthermore, if elasticity were utterly negligible, balloons would behave as complete rigid bodies - treated this way in the upcoming subsections.

2.2.1 Forces on the balloon

Important to note is that coordinate reference systems are a crucial aspect. A Cartesian coordinate reference frame is here chosen to express the three relevant forces appearing in balloons' flight paths: gravity, buoyancy and drag.

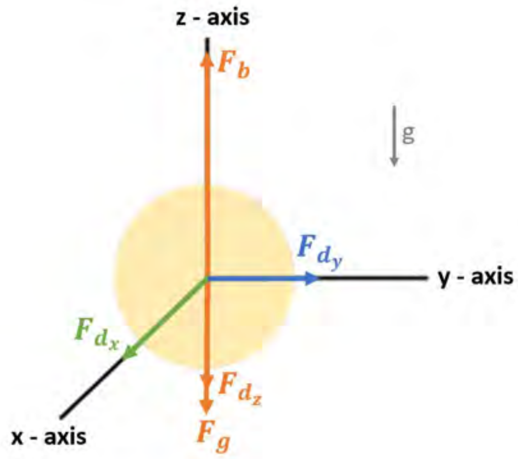

Figure 13: Sketch of balloon forces

⇒ The buoyant force $\mathbf{F_b}$ appears because of Archimedes' principle, above-mentioned in Section 2.1.3. As shown in Fig. 13, this lifting thrust acts in the z-direction and is given by Eq. 10. [24].

It must be remarked that $V(z)$, ρ_{air} and ρ_{gas} are all strongly dependent on altitude.

⇒ The downward force of gravity on the balloon $\mathbf{F_g}$, commonly named as weight, is opposed by the buoyant force. Denoted below with a negative sign. [24].

$$F_g(z) = -\, m_{sys}\, g\, z \tag{11}$$

To clarify terms, m_{sys} represents the total mass of the entire balloon-payload system. Furthermore, another fact worth mentioning is the 'gravity change with altitude'. The truth is that as the balloon rises, the gravity it experiences will progressively lessen. However, no model including this condition has already been developed. Therefore, a constant value of 9.80665 $\frac{m}{s^2}$ will be employed during the whole project.

⇒ The drag force $\mathbf{F_d}$ acts to oppose the balloon's velocity relative to the surrounding air, v_{rel}. Remembering mechanics of flight, $\mathbf{v_{rel}} = \mathbf{v}$ - $\mathbf{v_{wind}}$. However, v_{wind} is only taken into account in x- and y- directions for the sake of simplicity. Therefore, v_{wind} in the z-direction is set to be 0. [24].

Additionally, following Eq. 12 is written with a negative sign due to the fact that this last force acting on the balloon is going against the movement.

$$\mathbf{F_d}(\mathbf{x}, \mathbf{v_{rel}}) = -\frac{1}{2}\,\rho_{air}(z)\,C_D\,A(z)\,|\mathbf{v_{rel}}|\,\mathbf{v_{rel}} \tag{12}$$

Because of the quadratic dependence on velocity in previous Eq. 12 and the tendency to act in all three directions, this last force acting on the balloon plays a major role in determining its trajectory. [24].

It is noteworthy to highlight that latex or rubber weather balloons are widely modelled as spheres in terms of shape. As a consequence of assuming spherical volumes, balloons also adopt their drag coefficient, $c_D = 0.47$.

2.2.2 Equations of motion

Newton's Second Law is the base for the calculation of balloons' governing equations. Recalling it:

$$\sum_{i=1}^{n} \mathbf{F}_i = m\mathbf{a}$$

And applying it specifically to each direction:

$$m\ddot{x} = F_{d_x}\,x \tag{13}$$

$$m\ddot{y} = F_{d_y}\,y \tag{14}$$

$$m\ddot{z} = (F_{d_z} + F_g + F_b)\,z \tag{15}$$

One point worthy of comment is that the mass in question is identically the total mass of the balloon, $m = \frac{F_g}{g}$. However, it is true that as the balloon moves through a fluid which tends to drag some of the fluid along with it, a term named 'dragged air' or 'added mass', m_a should be appearing. m_a plus m would equal the 'virtual mass', m_v - the proper term that should be used in the equations of motion. Nevertheless, m_a is not taken into account in this project for the sake of simplicity. [24].

In addition, as Eqs. 13 and 14 reveal, balloon's horizontal equations of motion are only dictated by the drag force. Under these conditions, the horizontal velocity will rapidly converge to the surrounding air velocity from rest. As a consequence, it is reasonable to neglect balloon's horizontal component of the velocity to only take into consideration that of the ambient wind. [24].

Besides, it is vital to point out that balloon's trajectory is attached to the Earth's surface. Consequently, inertia forces should be considered in that case, remarking that Coriolis force would be the most significant one. Nevertheless, as the duration of the day is substantially greater than balloon's flight, the induced velocity would be accordingly smaller enough than the balloon's speed causing inertia forces to be utterly negligible.

2.3 Physics about non-elastic and elastic problems

Elasticity is defined to be the ability of a deformed material body to return to its original shape and size when the forces causing the deformation are removed. [25]. To properly address elastic effects in high altitude balloons so that a maximization of the upward lift to reach desirable altitudes is achieved, non-restoring and elastic models will be studied.

In order to see different behaviours in weather balloon's envelopes, it is appropriate to proceed on the basis that the following formula that establishes the total sum of pressures acting on a balloon holds:

$$p_{out}(z) = p_{in}(z) - p(\xi) \tag{16}$$

where:
- $p_{out}(z)$ and $p_{in}(z)$ are the external pressure exercised by the atmospheric air and the internal pressure exerted by the gas, respectively. In all cases, both pressures depend on the altitude, z.
- $p(\xi)$ is associated to be the inflation pressure when the balloon is rising up as a function of its stretch, ξ.

In the following subsections, a non-elastic model and two elastic "Mooney-Rivlin" and "Gent-Gent" models will be presented.

2.3.1 Non-restoring model

In non-elastic cases, $p(\xi)$ is set to be equal 0, as the body in question does not have the ability to behave or respond in an elastic manner. This means that differences in pressures between exterior and interior regions are zero fulfilling:

$$p_{out}(z) = p_{in}(z) \tag{17}$$

As just denoted, this model is characterized by neglecting inflation pressure or also called membrane pressure. Hence, to be able to see radius' change with altitude, initial and final balloon states must be equalized by using the ideal gas law - Eq. 1 - as shown below.
Remember that at the beginning of this chapter, it was mentioned that balloons are taken as spheres for the shake of simplicity. Therefore, $V_{balloon} \approx V_{sphere} = \frac{4}{3}\pi r^3$.

$$nR = \frac{pV}{T} = \frac{p_0 V_0}{T_0} \qquad \Rightarrow \qquad r = r_0 \left(\frac{p_0}{p} \cdot \frac{T}{T_0} \right)^{\frac{1}{3}} \tag{18}$$

2.3.2 "Mooney-Rivlin" and "Gent-Gent" elastic models

William Alexander Osborne (1873-1967), professor of physiology, noticed that rubber balloons had a peculiar mechanical response to inflation just by reference to the example of rubber party balloons. [26]. As everyone could have experienced at any time, the initial inflation requires a strong effort, but just until a limit instability is reached. After that inflection point, merely easing pressure is required to continue all the way to rupture, exactly when the elastic limit is encountered.

This pressure-radius relationship regarding non-linear elastic models were based on the idea of inflating a thin elastic finite thickness spherical shell. In this context, the next assumptions were considered:

- Materials of the shell are described to be incompressible, isotropic and hyperelastic. That means that any strain energy density function can be a candidate to predict the behaviour of a real blown-up material in circumstances in which direct experimental tests are impractical. [27].
- Normal stress components in membranes are small in comparison with circumferential stress components, which in other words means that only purely radial deformations have been studied. Mathematically, $r = r\,(r_0)$ where r and r_0 indicate 'deformed' and 'non-deformed initial' radii, respectively. [27].

Inasmuch as these elastic models have a rubber-like material that will progressively expand as altitude is gained, the inflation pressure $p\,(\xi)$ is then defined:

$$p\,(\xi) = \frac{t_0}{r_0\,\xi^2} \frac{\partial W}{\partial \xi} \tag{19}$$

where $\xi = r/r_0$, t_0 is the beginning undistorted thickness and W is the strain energy density function.

Be aware that p_{in} and p_{out} are computed differently. The internal pressure uses the ISA model, previously explained in Section 2.1.1. and the external pressure employs the ideal gas law - recall Eq. 1.

Other relevant parameters to be closely examined are the lifted mass by the helium balloon and its ascent velocity. [28]

On the one hand, the lifted mass is the amount of air displaced by the balloon. On the other hand, the rising speed v_z is acquired by making the lifted weight of air and the vertical drag equal.

$$m_{lifted} = \rho(z) \cdot V_{balloon} \qquad ; \qquad v_z = \sqrt{\frac{2\, m_{lifted}\, g}{c_D\, \pi\, \rho(z)\, r(z)^2}} \tag{20}$$

"Mooney-Rivlin" or "Gent-Gent" models have succeeded despite the fact that are developed within different approximations based on the same non-elastic spherical shell idea. It is justified just hereafter.

Mooney - Rivlin model, MR

In 1940, this model was suggested by Melvin Mooney. In 1948, Ronald Rivlin had already expressed it with regard to invariants I_1, I_2 and I_3, which are quantities that remain unchangeable under coordinate transformations. In the three-dimensional case, these parameters are defined as: [29]

$$I_1 = {\xi_1}^2 + {\xi_2}^2 + {\xi_3}^2 \tag{21}$$

$$I_2 = {\xi_1}^2\, {\xi_2}^2 + {\xi_2}^2\, {\xi_3}^2 + {\xi_3}^2\, {\xi_1}^2 \tag{22}$$

$$I_3 = {\xi_1}^2\, {\xi_2}^2\, {\xi_3}^2 \tag{23}$$

Mooney-Rivlin strain energy density function, W_{MR} is a function of the strain invariant of the left Cauchy-Green deformation tensor: [29]

$$W_{MR} = c_1\left({\xi_1}^n + {\xi_2}^n + {\xi_3}^n - 3\right) + c_2\left({\xi_1}^n\, {\xi_2}^n + {\xi_2}^n\, {\xi_3}^n + {\xi_3}^n\, {\xi_1}^n - 3\right) \tag{24}$$

where n, c_1, c_2 and J_m are positive constants. Just by substituting n=2, this model is obtained. Translated to terms of inflation pressure:

$$p\left(\xi\right) = \frac{2\mu t_0}{r_0}\left(\xi^{-1} - \xi^{-7}\right)\left(1 + \frac{(1-\gamma)}{\gamma}\xi^2\right) \tag{25}$$

where μ is the shear modulus and γ is a dimensionless parameter that depends on the balloon's envelope material.

Consequently, Eq. 25 is inserted in the main pressure equation - Eq. 16 - and only by replacing p_{in}, p_{out} and the just calculated $p\left(\xi\right)$, the radius evolution with altitude is given by:

$$p_{out}(z) - \frac{nRT(z)}{\frac{4}{3}\pi r^3} + \frac{2\mu t_0}{r_0}\left(\left(\frac{r_0}{r}\right) - \left(\frac{r_0}{r}\right)^7\right)\left(1 + \frac{(1-\gamma)}{\gamma}\left(\frac{r}{r_0}\right)^2\right) = 0 \tag{26}$$

Gent - Gent model, GG

Alan Gent proposed the use of a very simple phenomenological constitutive model mainly based on hyperelastic materials.

Gent-Gent strain energy density function, W_{GG} is designed for a singularity to occur if the first invariant of the left Cauchy-Green deformation tensor reaches a limiting value. It may be expressed in the form: [26]

$$W_{GG} = -c_1 \, J_m \, \ln\left(1 - \frac{{\xi_1}^2 + {\xi_2}^2 + {\xi_3}^2 - 3}{J_m}\right) + c_2 \, \ln\left(\frac{{\xi_1}^2 \, {\xi_2}^2 + {\xi_2}^2 \, {\xi_3}^2 + {\xi_3}^2 \, {\xi_1}^2}{3}\right) \tag{27}$$

where n, c_1, c_2 and J_m are also positive constants. To get GG model, c2 = 0.

This model is noted for integrating the concept of the elastic limit. However, to get the inflation radius, a similar approach to Mooney-Rivlin model is obeyed:

$$p\,(\xi) = \frac{2\mu t_0}{r_0}\left(\xi^{-1} - \xi^{-7}\right)\left(\frac{J_m}{J_m - (2\xi^2 + \xi^{-4} - 3)}\right) \tag{28}$$

where J_m is the limiting value or so-called Gent parameter. For this value, the maximum allowable stretch is reached: $J_m = 2\ {\lambda_m}^2 + {\lambda_m}^{-4}$ - 3. [29].

In order to get the radius evolution, the same procedure as in Moonley-Rivlin model has to be followed leading to:

$$p_{out}(z) - \frac{nRT(z)}{\frac{4}{3}\pi r^3} + \frac{2\mu t_0}{r_0}\left(\left(\frac{r_0}{r}\right) - \left(\frac{r_0}{r}\right)^7\right)\frac{J_m}{J_m - (\,2\,(\frac{r}{r_0})^2 + (\frac{r}{r_0})^{-4} - 3\,)} = 0 \tag{29}$$

2.4 High-altitude balloon Trajectory Software

2.4.1 Wind data source - NOAA

The “National Oceanic and Atmospheric Administration” - NOAA - is an American scientific agency on the inside of the US Department of Commerce that addresses issues of worldwide concern such as dangerous weather in charts seas or oceans, or studies of the major waterways and atmospheric conditions all over the globe. This organization ensures the protection of oceanic and coastal wealth, as well as the awareness-raising and commitment to environmental matters. [30].

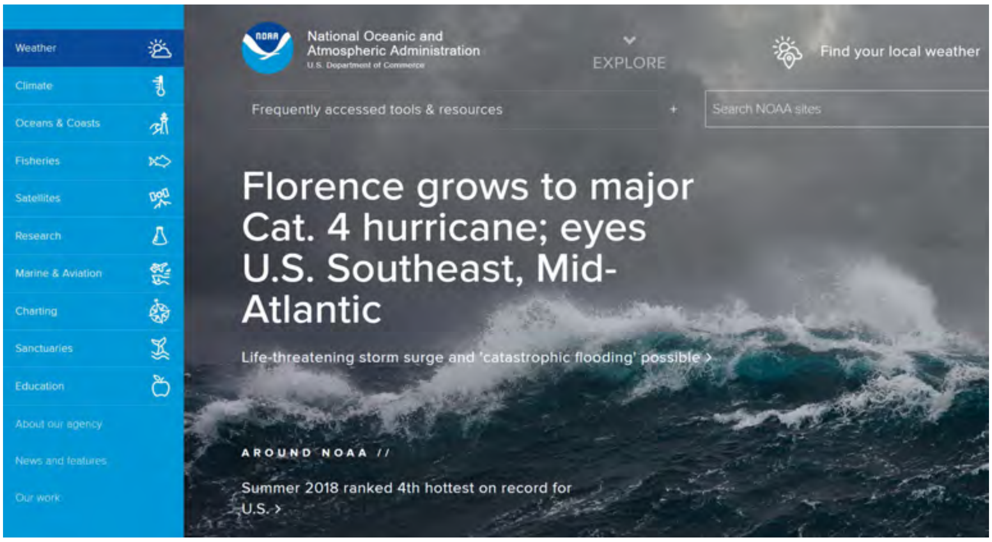

Figure 14: NOAA's main web-page [30]

NOAA's mission focuses on 9 key areas as appreciated on the left-hand side of Fig. 14. "Weather", "Climate", "Oceans & Coasts", "Fisheries", "Satellites", "Research", "Marine & Aviation", "Charting" and "Sanctuaries" were officially formed in 1970 and still today continue serving and providing these functions. [30].

In the subject matter hereof, NOAA is essential to act as a source of supplying wind data information so that estimations of wind speeds in the different atmospheric layers can be done. These forecasts are of great value in cases of strong gusts of wind or squalls.

To achieve this, NOAA provides free access to the "Climate Data Online" - CDO - which is the main general search-page for locating global and regional weather and climate data inside the "National Climatic Data Center" - NCDC. [31].

All this data is provided through a servers' network called "NOAA Operational Model Archive and Distribution System" - NOMADS. [32]. These files are downloaded in a .0p25 format, which denotes that all data stored is collected every 0.25° in latitude and 0.25° in longitude.

Figure 15: NOAA's trademark [30]

2.4.2 MATLAB predictor

Coordinate reference system conversion

In the first place, it should be emphasized that a coordinate reference system conversion is needed. Latitude, longitude and height are expressed in an Ellipsoidal system of coordinates, whereas balloon's dynamics are denoted in Cartesian ones. See Fig. 16. Therefore, a changeover going from a randomly chosen point on Earth X_0, Y_0 and Z_0 to φ_0, λ_0, h_0 is required as trajectory plots are requested in this second referenced coordinate frame. [33].

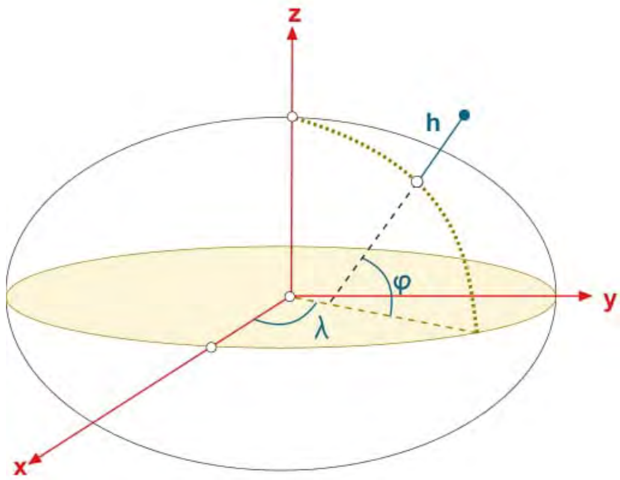

Figure 16: Ellipsoidal and Cartesian coordinates [33]

R_v and R_u are set to be the coefficients of transformation from Cartesian to Elliptic coordinates and represent the displacements in latitude and longitude coordinates as follows:

$$R_v = \frac{\sqrt{(X_{\Delta\varphi} - X_0)^2 + (Y_{\Delta\varphi} - Y_0)^2 + (Z_{\Delta\varphi} - Z_0)^2}}{\Delta} \tag{30}$$

$$R_u = \frac{\sqrt{(X_{\Delta\lambda} - X_0)^2 + (Y_{\Delta\lambda} - Y_0)^2 + (Z_{\Delta\lambda} - Z_0)^2}}{\Delta} \tag{31}$$

where $[X_{\Delta\varphi},\ Y_{\Delta\varphi},\ Z_{\Delta\varphi}]$ and $[X_{\Delta\lambda},Y_{\Delta\lambda},Z_{\Delta\lambda}]$ symbolize a position on the Earth's surface after a small displacement, Δ from their initial points, φ_0 and λ_0:

$$\Delta\varphi = \varphi_0 + \Delta \quad ; \quad \Delta\lambda = \lambda_0 + \Delta$$

Finally reaching latitude, φ and longitude, λ in radians: $\varphi = \frac{y}{R_v}$; $\lambda = \frac{x}{R_u}$

Self-developed interpolation model

This MATLAB-implemented model relies on the aforementioned wind information extracted from NOAA's database. [32]. This data service is updated every six hours daily, specifically at 00:00, 06:00, 12:00 and 18:00. Actually, this web-page covers a time-length of around 7 days and once the eighth day aims to transfer its wind data, the oldest computer file is overlapped losing that day's information permanently.

However, to be able to read all these files, MATLAB has to firstly run "nctoolbox", which is a storing feature that provides read-only access to common data-sets' models.

The self-developed trajectory predictor proposes an interpolation of the velocity field u and v by inputting certain latitude and longitude coordinates and the height in meters above mean sea level - AMSL. u and v components store the isobaric wind data needed for the determination of the rising layers and h_p vector archives pressure-altitude information.

This interpolation is needed as only 31 wind values are taken inside those variables, even though a distance of 50 kilometers height from sea level has been considered.

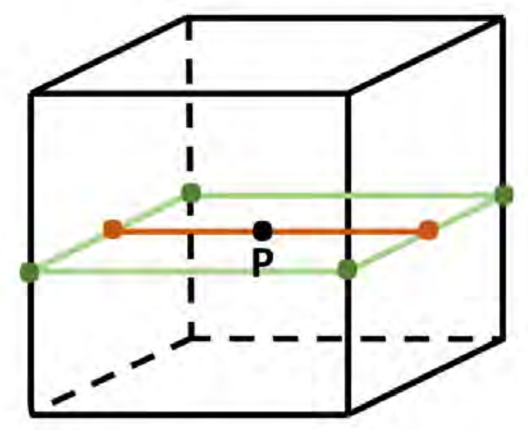

Figure 17: Interpolation model concept

Consequently, a guidance on the steps followed in the computational code will be given:

1. Get global variables of h_p, latitude and longitude coordinates from data files as matrices of gigantic data bases are utilized.
2. Compute the pressure for a given altitude. At that time, an appearing point P for that certain altitude is positioned inside a virtual box from the infinite cubes the code encompasses with all their corresponding data.
3. Then, find the indexes in the pressure heights that enclose that selected point P. See four points in green colour in Fig. 17.
   Afterwards, search the indexes in longitude that surround the inputted limiting longitudinal value - see two points in orange colour in Fig. 17.
   Finally, look for for the indexes in latitude that encircle the inputted limiting latitudinal value - See orange line making a segment in Fig. 17.
4. Calculate a linear interpolation of the velocities; firstly in height, then in longitude and eventually in latitude.

The complete interpolation cipher along with the main script used to plot and depict results' section are found in Appendix B.

3 Results

3.1 Non elastic and elastic behaviours with altitude

As the document has previously unfolded in a general context, there exist two possibilities regarding material balloons' envelopes: elastic or not. This section will evaluate the effects of the forces exerted on arbitrary envelopes to see whether elasticity is relevant or not in the performance of their trajectories.

3.1.1 Radius evolution

The three outcomes shown in Fig. 18 are obtained by solving Eq.17 for the non-elastic model and Eqs. 26 and 29 for the two Mooney-Rivlin and Gent-Gent elastic models, respectively.

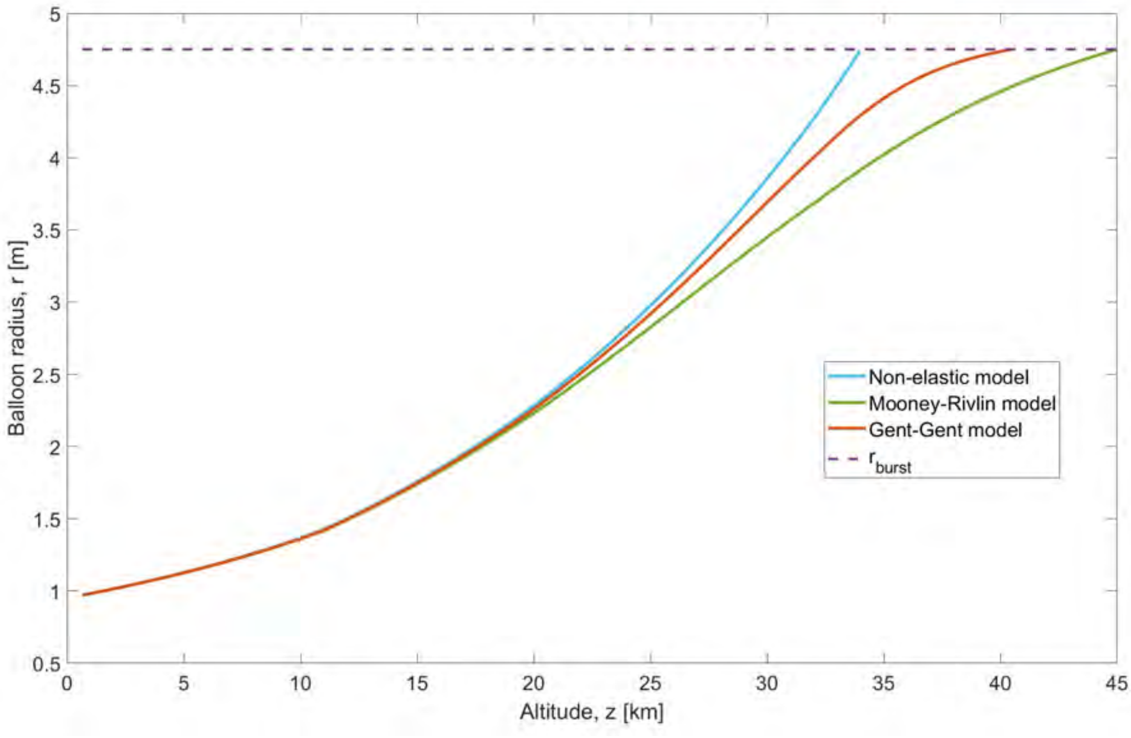

Figure 18: Balloon radius evolution with altitude

An important feature to mention is r_{burst}, which is imposed by the manufacturer in the specification "Diameter at burst = 9.5 m" - See Appendix A. Therefore, producer's limitation matches with the appreciated value appearing in Fig. 18 ensuring an $r_{burst} = 4.75\, m$. Once the balloon explodes, higher or smaller distances are arrived at depending on whether the balloon is made of one material or another.

In the case of the non-restoring model, an altitude of 34 km is encountered, while approximately 40 km are found for Gent-Gent model and around 45 km are achieved by Mooney-Rivlin elastic model. The fact that Mooney-Rivlin and Gent-Gent are not taken into account drag during the ascent might explain why elastic models reach higher altitudes than non-elastic models for a certain fixed radius. The altitude range in which this project works covers from 0 to a maximum of 34 km height AMSL. Consequently, the balloon for this project has not taken into account elasticity. Additionally, remember that this balloon is made of natural rubber latex and is closed-type.

On the other hand, if an altitude of 30 km is fixed, elastic models reach smaller radii: ≈ 3.25 m for Mooney-Rivlin and ≈ 3.5 m for Gent-Gent, whereas ≈ 3.75 m is attained for the non-elastic model. This could be explained because of the fact that the greater pressure differences are, the higher internal forces press the envelope of the balloon causing a reduction in the radius expansion.

3.1.2 Inflation or membrane pressure

With regard to the inflation pressure $p(\xi)$ of the non-elastic model, balloon pressure differences are clearly zero, as next Fig. 19 depicts and as Eq. 17 dictated previously. Concerning MR and GG elastic models, progressive changes of the external and internal pressure behaviours versus altitude are depicted in the following graph.

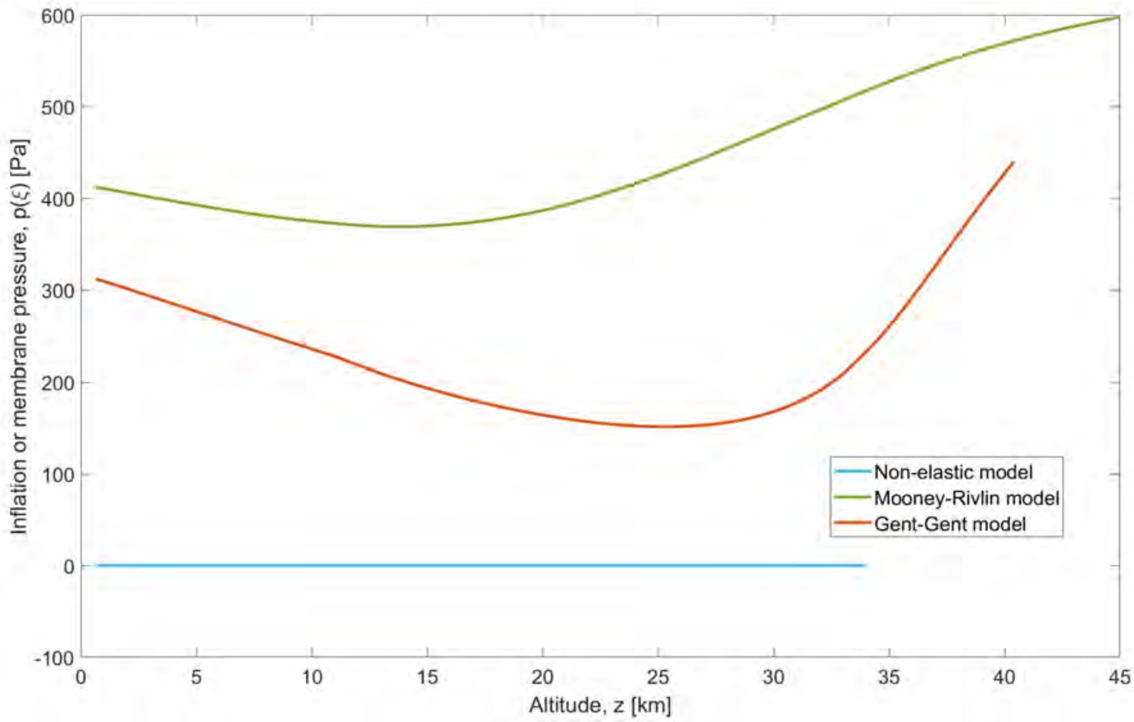

Figure 19: Inflation or membrane pressure with altitude

For a sea-level altitude, MR model accomplishes values around 400 Pa whereas GG model starts with a lower inflation pressure of 300 Pa. However, pressures at sea level are not here the greatest concern. Once balloons made of elastic materials arrive at vertical distances of approximately 40 km, external and internal pressures are much intensified. This deepening could be explained because membrane pressures at those altitudes are much smaller than the atmospheric existing pressures causing the difference between both pressures to be pretty much more noticeable.

With these outcomes, elastic effects are distinctly claimed not to be considered in the balloon's flight-path of this project as its bursting altitude is at maximum 34 km, which means never getting as high as 40 km.

3.1.3 Lifted mass

The term "lifted mass" concerns specifically to the mass of volume displaced by the balloon. With regard to the non-restoring model, m_{lifted} remains constant as $p(\xi)$ equals 0 - See Fig. 20. Referring to the elastic models, a similar falling down behaviour is encountered as altitude rises. This is because of the fact that the density lessens in a greater extent than the volume expands provoking m_{lifted} to decline at higher heights AMSL. The most diminished number of kilograms, very clearly reached at the highest altitudes as seen in Fig. 20, determines the maximum weight the balloon can actually raise.

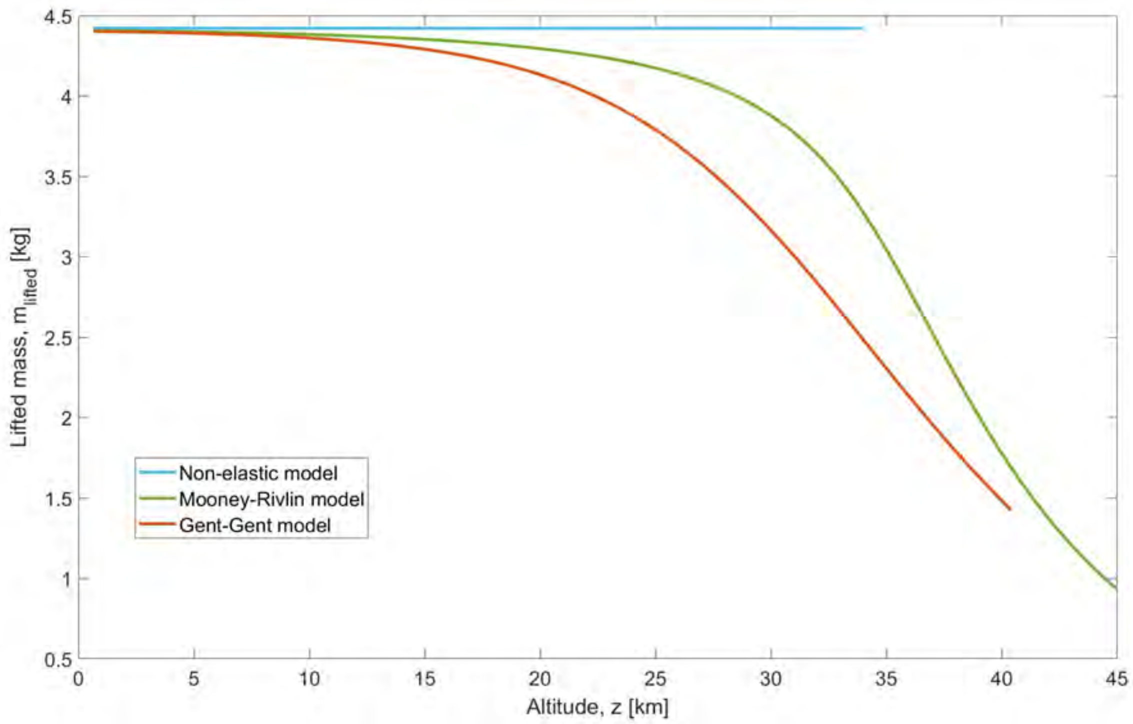

Figure 20: Lifted mass with altitude

As an exemplification to discuss above results, GG model decreases m_{lifted} from around 4.4 kg to 3.2 kg at the burst altitude ($z_{burst} = 34$ km) and up to 1.7 kg at 40 km, when the balloon supposedly explodes. On the other hand, MR model drops from the same point until 2.5 kg at z_{burst} and until 0.88 kg at 45 km, when the envelope breaks. Under these set of decreasing conditions, climbing performances are said to be not affected, but flight paths might.

3.1.4 Rate of ascent

As expected, the higher balloons raise, the faster their ascent velocities get. This is accounted for the fact that ascent velocities rise so quickly to the quasi-steady value that balloons are nearly at equilibrium at all times.

Additionally, it is important to highlight that an average ascent rate of 5 m/s is widely common to be assumed. As it happens, HABHUB predictor uses this tool. However, this is not the case as an starting ascent velocity of around 7.5 m/s and an ending speed of $\approx$ 16.2 m/s is represented in Fig. 21. This is supposedly much more accurate than taking the aforementioned mean value velocity, however there also exists downsides in the present study as gravity variation with altitude is not taken into consideration, as beforehand stated.

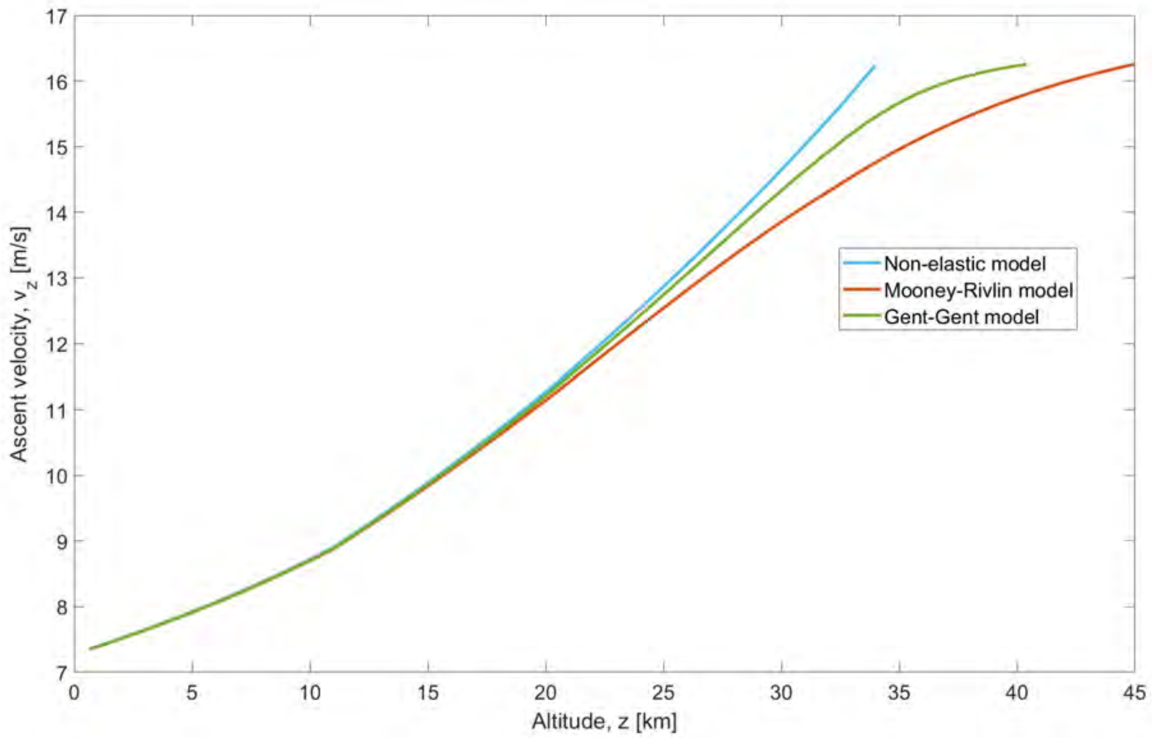

Figure 21: Ascent velocity with altitude

3.2 Trajectory prediction

This section shall illustrate position and velocity behaviours with time of a randomly chosen balloon flight in both horizontal and vertical motions, as well as a 3D trajectory plot of that supposed trajectory evolution in φ, λ and z coordinates.

As an example to showcase a balloon's position and speed forecasts, Villanueva de la Cañada coordinates have been introduced in the self-developed MATLAB preditor on the randomly selected Sep 15$^{\text{th}}$ 2018. The following Fig. 22 and Fig. 23 show these changes with time hereunder.

Latitude	**Longitude**	**Altitude [m]**
40.440684	-3.989327	650

Table 5: Villanueva de la Cañada position and altitude

Horizontal motion

The horizontal motion encompasses both latitudinal and longitudinal coordinates - φ, λ. Furthermore, trajectories and speeds are essentially only dependent on wind currents, as already specified on Section 2.

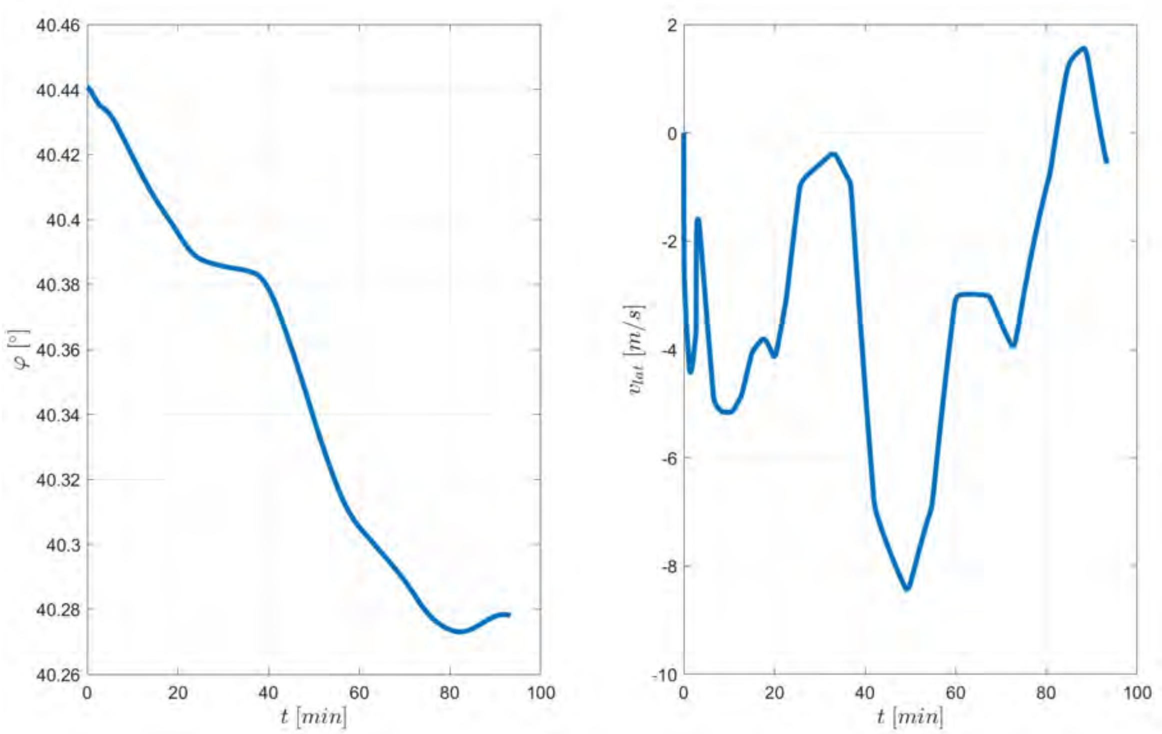

Figure 22: Position and velocity with respect to the latitudinal coordinate

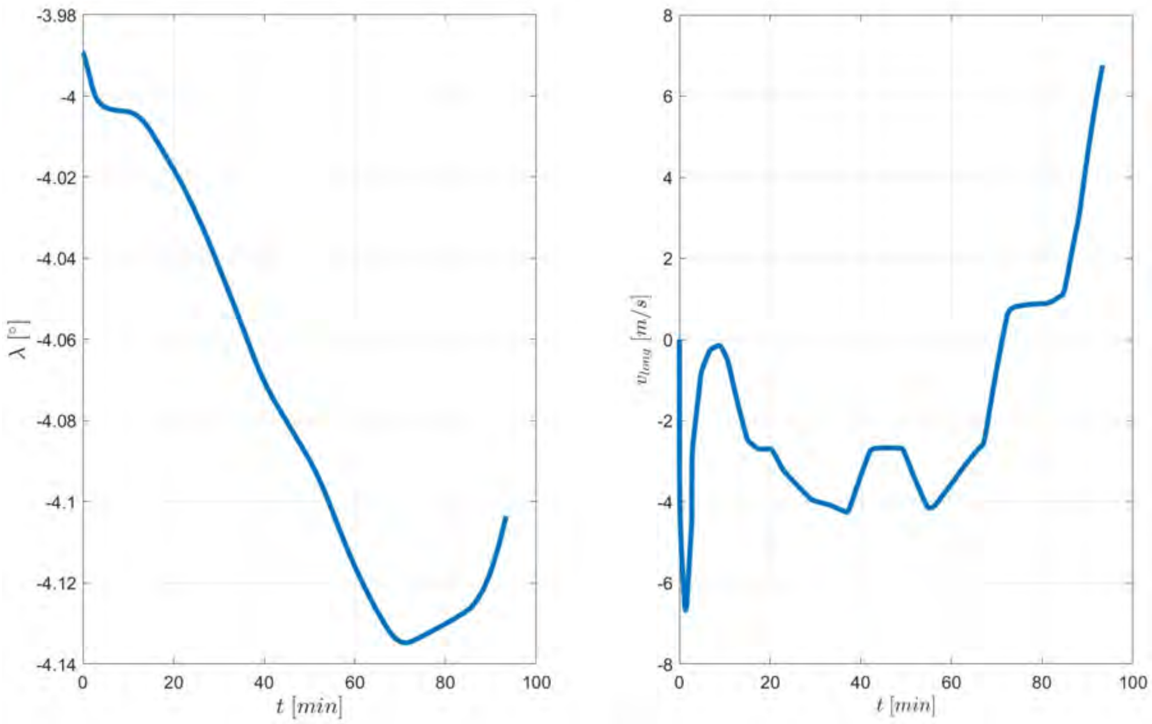

Figure 23: Position and velocity with respect to the longitudinal coordinate

Concerning latitudinal and longitudinal flight paths, it is fairly visual that this balloon moves really little regarding these two coordinates. With respect to φ, only latitudes from 40.44° to 40.26° have been travelled. And with regard to λ, solely longitudes from -3.99° to around -4.14° have been swept.
Regarding the self-developed interpolation model, it can be said that high-altitude balloons do not leave the created virtual box neither in latitude, φ nor in longitude, λ.

According to both velocity progressions with respect to time, it must be accounted for the fact that peaks might show an irregular profile. These several irregularities may be clarified by noticing that there exist layers within the Earth atmosphere that go faster that others. Nevertheless and although these curves are kind of sudden, continuity is fulfilled all the time.
Additionally, it might be also noted that perceptible negative speeds appear in both Fig. 22 and Fig. 23. Those velocities only denote that the balloon is moving in the opposite direction to its normal flight path, just following wind directions.

Vertical motion

The vertical motion comprehends the z coordinate or, in other words, the so-called altitude, z. However, trajectories and speeds are not determined at all by any wind in this straight up motion. Several studies claim that the order of magnitude of the wind within this coordinate is much smaller in comparison with the proper upwards movement of the balloon itself.

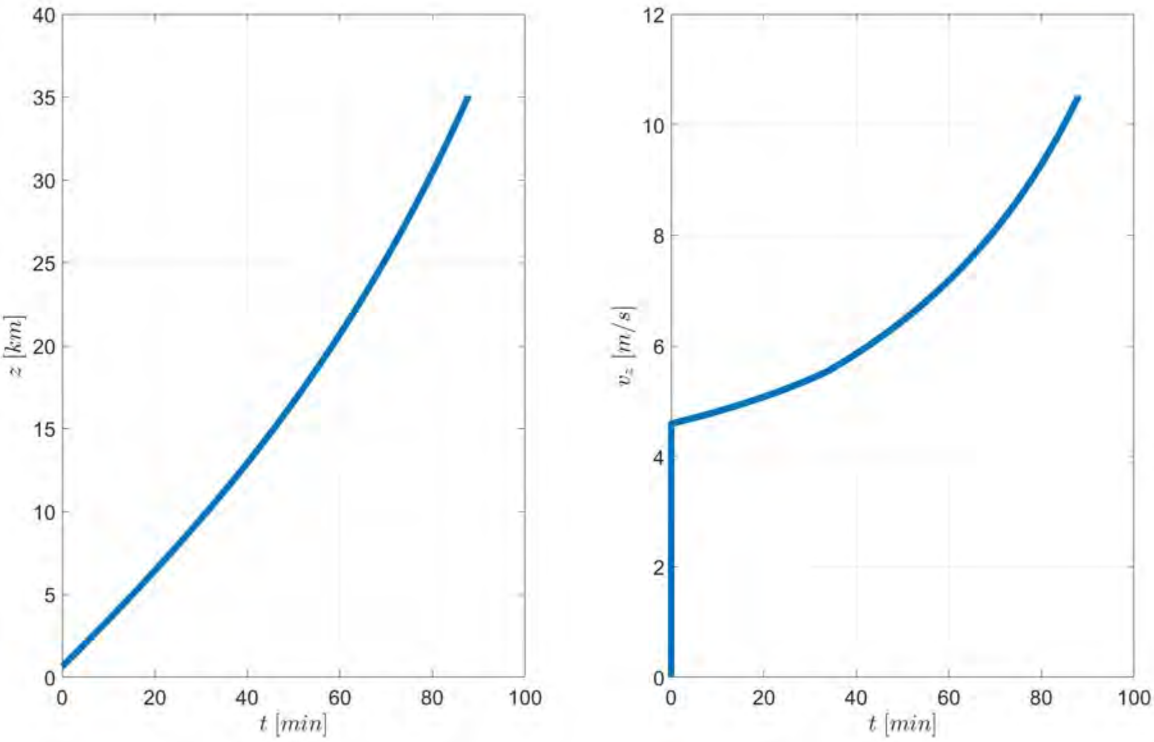

Figure 24: Position and velocity with respect to the z-coordinate

Following the left graph of Fig. 24, it is clearly seen that the balloon climbs progressively as expected until it supposedly explodes at an altitude a little bit higher that 34 km in approximately one hour and a half of ascent.

Reading the right graph of Fig. 24, it can be plainly observed that right after the balloon release in Villanueva de la Cañada, which as previously said has 650 m of height AMSL, an ascent velocity of 5 m/s is immediately acquired because of the initial amount of helium inside it. Just after, v_z rises until almost 11 m/s, where the balloon begins to fall down back to the Earth's surface. This growth in velocity may be expounded on the fact that the buoyant force - F_b - is larger that the drag force - F_b, which decreases as height AMSL increases, because balloon's envelope volume expands faster than density decreases during the climb.

Flight path evolution

Fig. 25 symbolizes a 3-dimensional plot of the flight path of the same example from above. By definition, velocity fields are integrated to yield to trajectories. And although velocities might sometimes display fluctuations, flight paths are averages and continuous every time.

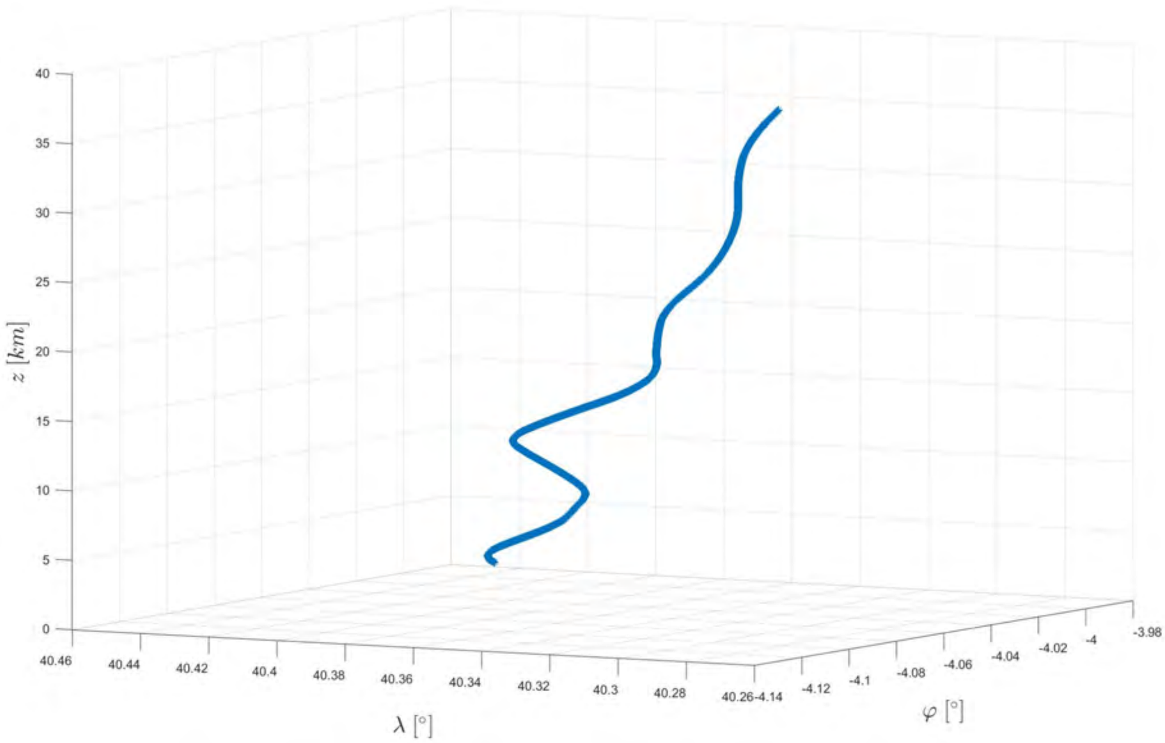

Figure 25: Randomly chosen 3D trajectory evolution

3.2.1 Accuracy of the interpolation model

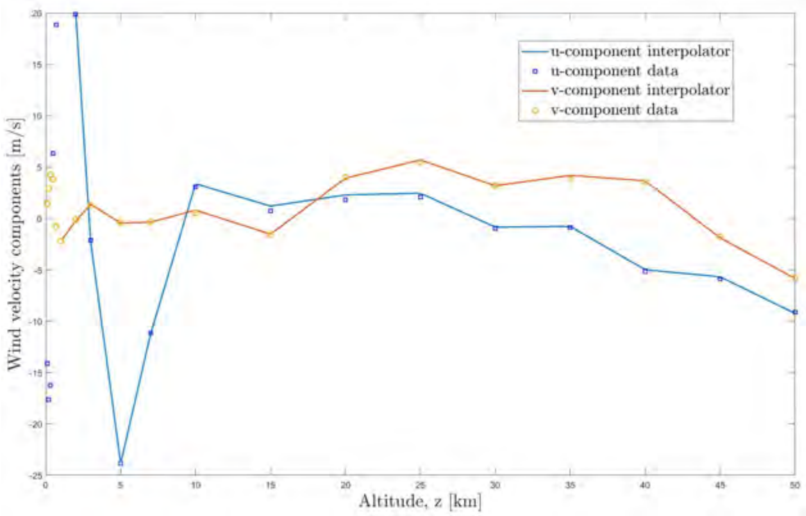

Figure 26: Preciseness of the interpolation model

Fig. 26 assures that this self-developed predictor is probable to meet objectives. The compliance with the already established data files is presented above.

3.3 Comparison of present and existing prediction models

With the goal of proving that any balloon's flight path within this self-developed MATLAB predictor is suitably calculated and implemented, several randomly chosen trajectories are compared with the earlier mentioned "HABHUB Balloon Tracker".

This HABHUB tracker is based on controlling all worldwide stratospheric balloons' paths in real time. The evolution with time of these balloons in the sky can be also visualized not only at its own webpage, but also in other applications such as Google Earth Pro. This is done to plot quite a lot more balloon trajectories at the same time and place. To move all these balloons' monitoring files, a direct download from HABHUB's webpage creates a ".kml file" that stores all necessary information.

The two different already explained ways of plotting balloon trajectories are shown below in Fig. 27 and 28:

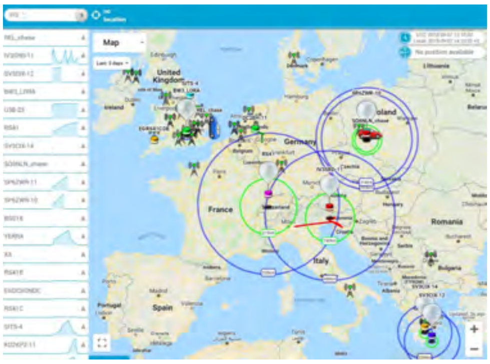

Figure 27: Balloon Tracker on HABHUB's webpage [14]

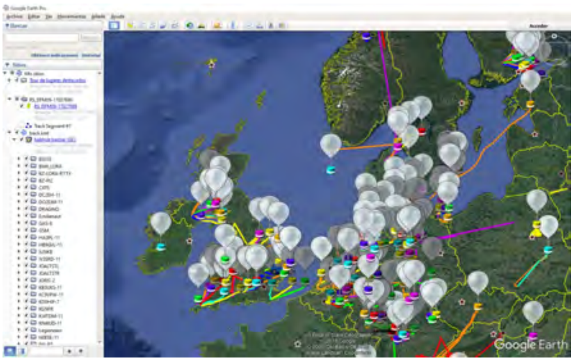

Figure 28: HABs' tracking opened with Google Earth Pro

At this stage, an important factor to be mentioned is that several paths have been presented along this project's duration although only these two upcoming most visual examples are been showcased.

Additionally, it is important to recall that the interpolation model does not take into account any phase after the balloon's envelope rupture or breaking point. Therefore, displayed MATLAB flight paths never present balloons' lowering processes in the following figures.

Figure 29: Top view - worldwide balloons

It is noteworthy emphasizing that following RS-P0720902 and RS-N4010512 balloons begin collecting values for their track record when there is a direct vision line with their monitoring stations. That is the reason why trajectory recordings start at those high altitude AMSL - See “Altitude [m]” in Tables 6 and 8.

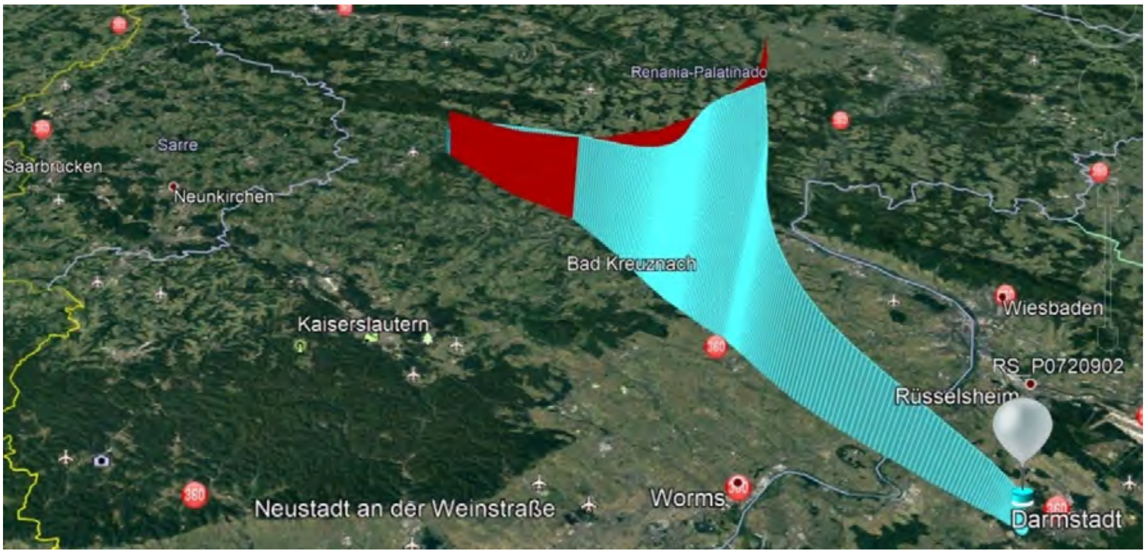

Figure 30: Comparison of “HABHUB Tracker” with “MATLAB predictor”

HAB name	Latitude	Longitude	Altitude [m]	Launch date & time
RS-P0720902	49.695711	7.337229	7093	Sep 16th at 07:02

Table 6: Balloon data - Launch in Germany

Fig. 30 represents a comparison between a flight path of the above explained balloon - see Table 6 - with the “HABHUB Tracker” and the “MATLAB predictor”. It can be easily seen that the red trajectory corresponds to the MATLAB forecast whether the cyan tracking matches the above-named online predictor.

Moreover, both the tracker and the predictor expose pretty similar trajectories although slight differences could be also noted. These differentiations may be because a real monitoring balloon evolution and its previous forecast have been compared, and not two predictors that are much prone to provide more alike behaviours. Nevertheless, very comparable similarities regarding bursting altitudes in this particular balloon are accomplished with both tracker and predictor.

Other data of importance concerning balloon RS-P0720902 is contained in Table 7:

Speed [km/h]	External temperature [K]	Humidity [g/m^3]
14.7	251.95	-1.0

Table 7: Additional balloon information - Release in Germany

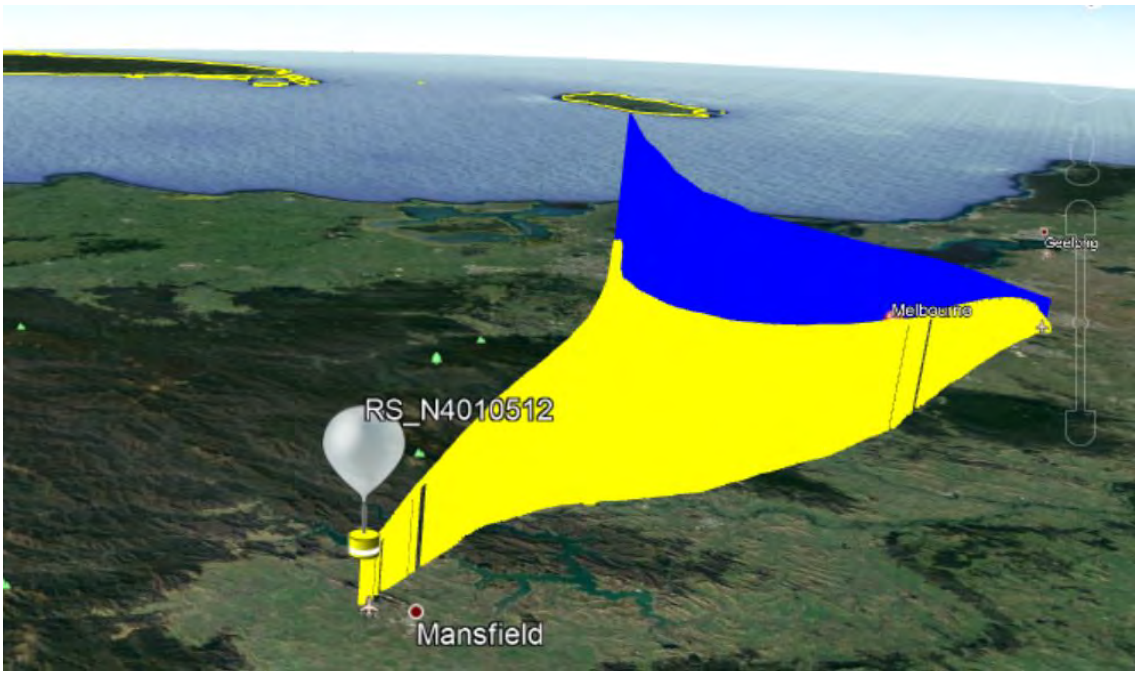

Figure 31: Another comparison of "HABHUB Tracker" with "MATLAB predictor"

HAB name	**Latitude**	**Longitude**	**Altitude [m]**	**Launch date & time**
RS-N4010512	-37.673333	144.843333	4211	Sep 16^{th} at 13:10

Table 8: Balloon data - Launch in Australia

Fig. 31 is another example that presents a "HABHUB Tracker" and "MATLAB predictor" comparison. In this case, yellow trajectory matches the MATLAB forecast while blue tracking corresponds to the already cited online predictor.

Furthermore, the same as in Fig. 6 happens, really similar trajectories are encountered although small differences could be noticed too. In this particular case, it might be due to the fact that only 37 wind data files where used inside this self-developed interpolation model. As these data is difficult to be correctly stored on their specific layers, not all the existing wind information has been considered in these MATLAB scripts. Even so, really equivalent flight paths are attained - See Fig. 31.

Other data of significance about this specific balloon, RS-N4010512 is included in Table 9:

Speed [$^{km}/_{h}$]	**External temperature [K]**	**Humidity** [$^{g}/_{m^3}$]
13	264.25	-1.0

Table 9: Additional balloon information - Release in Australia

4 Regulatory framework

Weather ballooning is a thrilling activity that affords a great amount of opportunities for both scientific researches and educational purposes. However, it is not without risk to cross. Balloons in ascending or descending phases, or even in the most dangerous part of their flights, landing approaches to the Earth's surface, could collide with whatever there is in their flight paths and become a hazard to the Air Traffic Management industry.

As a consequence and from a users' perspective, safety issues are a foremost concern inside modern societies and clearly, precautions have to be taken without the slightest doubt. Legally binding European treaties concerning airspace restrictions claim that every State has its own sovereignty over their aerial territories. [34]. That is why Member States could set certain areas through which flight is "danger", "prohibited" or "restricted". Even though this regulation is not exactly precise and that depends on each country, the governmental law tries hard to guarantee the globally sought-after safety.

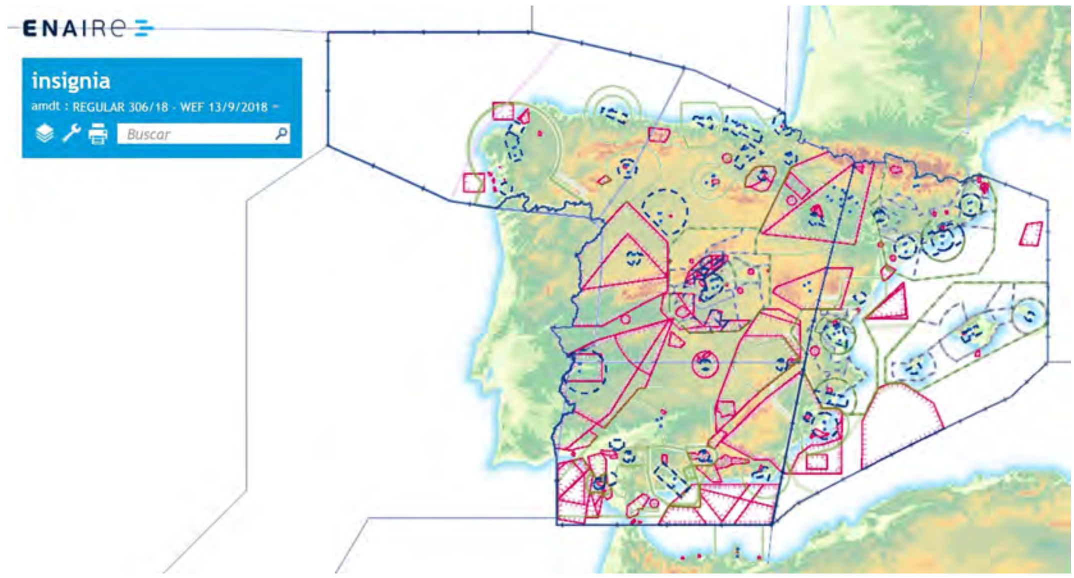

Figure 32: Spanish "danger", "prohibited" and "restricted" areas [35]

ENAIRE or previously called AENA ("Aeropuertos Españoles y Navegación Aérea") is the air navigation entity that enables en-route, approach and aerodrome control services within Spain and Western Sahara. This institution developed an interactive map that provides free and open data of air traffic named "ENAIRE Navigator". All users can display these three aforementioned areas as depicted in Fig. 32. [35].

In addition, ENAIRE has periodicals disclosed called "Aeronautical Information Publications España" - AIP España, where the already anticipated possibilities of airspace are explained: [36]

- Danger or Delta area (D): *"an airspace of defined dimensions within which activities dangerous to the flight may exist at specified times"*

AIP ENR 5.1-13
ESPAÑA 17-AUG-17

ZONAS PELIGROSAS / DANGER AREAS

IDENTIFICACIÓN Y NOMBRE - Límites laterales IDENTIFICATION AND NAME - Lateral limits	Límite superior Upper limit Límite inferior Lower limit	Observaciones / Remarks (Hora de actividad, tipo de actividad, naturaleza del peligro) (Time of activity, type of activity, nature of hazard)
LED1 CERRO MURIANO (Córdoba) 380400N 0045100W; 380500N 0044800W; 380300N 0044200W; 380000N 0044600W; 380400N 0045100W.	FL 180 SFC	Ejercicios de tiro terrestre, tiro aire-tierra y bombardeo / Ground firing, surface-to-air firing and bombing exercices. MON/FRI: HJ, EXC HOL. Otras actividades anunciadas por NOTAM / Other activities announced by NOTAM. Coordinación con / Coordination with: Sevilla ACC.

Figure 33: AIP España - Example of a Delta area [36]

- Prohibited or Papa area (P): *"an airspace of defined dimensions, above the land areas or territorial waters of a State, within which the flight is prohibited"*

AIP ENR 5.1-3
ESPAÑA WEF 17-AUG-17

ZONAS PROHIBIDAS / PROHIBITED AREAS

IDENTIFICACIÓN Y NOMBRE - Límites laterales IDENTIFICATION AND NAME - Lateral limits	Límite superior Upper limit Límite inferior Lower limit	Observaciones / Remarks (Hora de actividad, tipo de restricción, naturaleza del riesgo, riesgo de interceptación) (Time of activity, type of restriction, nature of hazard, risk of interception)
GMP21 355647N 0052900W; 355246N 0053436W; 355054N 0053232W; 355456N 0052703W; 355647N 0052900W.	FL 240 SFC	Prohibido el sobrevuelo / Overflying is prohibited. Esta zona se publica en AIP-ESPAÑA por acuerdo con Marruecos / This area is published in AIP-ESPAÑA by agreement with Morocco. Permanente / Permanent.

Figure 34: AIP España - Example of a Papa area [36]

- Restricted or Romeo area (R): *"an airspace of defined dimensions, above land areas or territorial waters of a State, within which the flight is restricted in accordance with certain specified conditions"*

AIP ENR 5.1-5
ESPAÑA WEF 17-AUG-17

ZONAS RESTRINGIDAS / RESTRICTED AREAS

IDENTIFICACIÓN Y NOMBRE - Límites laterales IDENTIFICATION AND NAME - Lateral limits	Límite superior Upper limit Límite inferior Lower limit	Observaciones / Remarks (Hora de actividad, tipo de restricción, naturaleza del riesgo, riesgo de interceptación) (Time of activity, type of restriction, nature of hazard, risk of interception)
GER11 MELILLA La totalidad del territorio de soberanía española alrededor del punto / All of Spain's sovereign territory around the point 351700N 0025500W.	UNL SFC	Prohibido el sobrevuelo / Overflying is prohibited. Permanente / Permanent. Autorizados los vuelos con destino/procedencia Melilla AD / Flights authorised with destination/departure from Melilla AD.

Figure 35: AIP España - Example of a Romeo area [36]

Recalling "Villanueva de la Cañada", the place where the 1600g meteorological balloon for this project is going to be launched, Fig. 36 shows that any area above this flight territory in question appears to have neither restrictions nor limits. Furthermore, not only rules are not in this position imposed but also neither mountains nor high elevations interpose this balloon's trajectory. Hence, the balloon could have flown without any problem on September 13$^{\text{th}}$ 2018 around 18:35 with "NOOA's Operational Model Archive and Distribution System" - NOMADS - wind data.

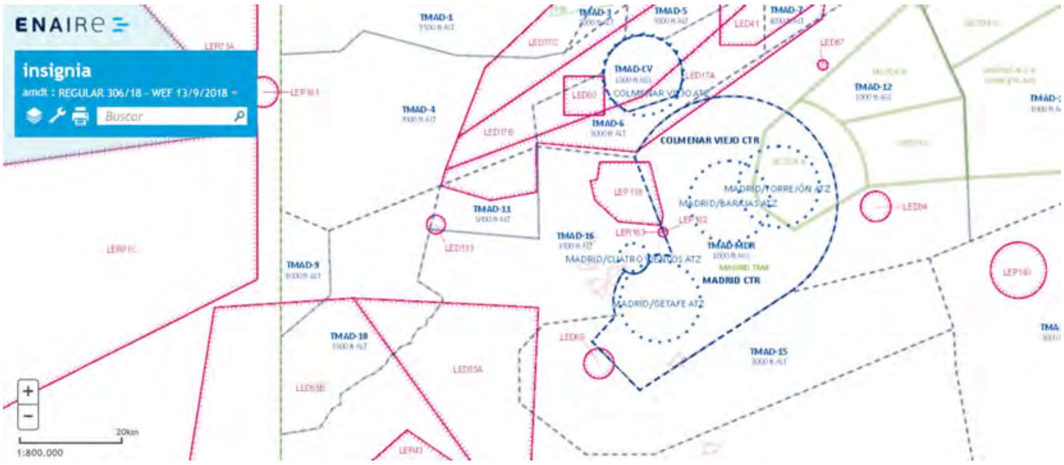

Figure 36: Villanueva de la Cañada and surroundings [35]

On the other hand, the "European Aviation Safety Agency" - EASA - is the institution within the member countries of the European Union - EU - in charge of making the governing rules and regulations so that real-world air traffic complies with global safety standards. [37].

Although EASA developed a document called "Certification Specifications (CS) and Acceptable Means of Compliance (AMC) for Free Gas Balloons - CS-31GB" comprehending and covering all their operational rules, there is nothing inside that document that elaborates specifically on stratospheric balloons and not only on the unmanned gas type. [38] - [39]. For this reason, American regulatory frameworks from aviation entities, such as the Federal Aviation Administration - FAA or the Federal Communications Commission - FCC have been taken into account to identify which regulations and laws for high altitude balloons exist up until now.

Hence, applicable safety standards for stratospheric ballooning are outlined as follows in accordance with, as mentioned above:

- The FCC (Title 47 → Chapter I → Subchapter B → Part 22 → Subpart H: Cellular Radiotelephone Service → §22.925) [40].
- The FAA (Title 14 → Chapter I → Subchapter F → Part 101 → Subpart D: Unmanned Free Balloons → §101.31, §101.33, §101.35, §101.37 and §101.39) [41].

§22.925 Prohibition on airborne operation of cellular telephones.

Cellular telephones installed in or carried aboard airplanes, balloons or any other type of aircraft must not be operated while such aircraft are airborne (not touching the ground). When any aircraft leaves the ground, all cellular telephones on board that aircraft must be turned off. The following notice must be posted on or near each cellular telephone installed in any aircraft:

"The use of cellular telephones while this aircraft is airborne is prohibited by FCC rules, and the violation of this rule could result in suspension of service and/or a fine. The use of cellular telephones while this aircraft is on the ground is subject to FAA regulations."

§101.31 Applicability.

"This subpart applies to the operation of unmanned free balloons. However, a person operating an unmanned free balloon within a restricted area must comply only with 101.33 (d) and (e) and with any additional limitations that are imposed by the using or controlling agency, as appropriate."

§101.33 Operating limitations.

"No person may operate an unmanned free balloon-"

(a) *"Unless otherwise authorized by Air Traffic Control - ATC, in a control zone below 2,000 feet above the surface, or in an airport traffic area;"*

(b) *"At any altitude where there are clouds or obscuring phenomena of more than five-tenths coverage;"*

(c) *"At any altitude below 60,000 feet standard pressure altitude where the horizontal visibility is less than five miles;"*

(d) *"During the first 1,000 feet of ascent, over a congested area of a city, town, or settlement or an open-air assembly of persons not associated with the operation; or"*

(e) *"In such a manner that impact of the balloon, or part thereof including its payload, with the surface creates a hazard to persons or property not associated with the operation."*

§101.35 Equipment and marking requirements.

(a) *"No person may operate an unmanned free balloon unless-"*

(1) *"It is equipped with at least two payload cut-down systems or devices that operate independently of each other;"*

(2) *"At least two methods, systems, devices, or combinations thereof, that function independently of each other, are employed for terminating the flight of the balloon envelope; and"*

(3) *"The balloon envelope is equipped with a radar reflective device(s) or material that will present an echo to surface radar operating in the 200 MHz to 2700 MHz frequency range."*

The operator shall activate the appropriate devices required by paragraphs (a) (1) and (2) of the previous section when weather conditions are less than those prescribed for operation under this subpart, or if a malfunction or any other reason makes the further operation hazardous to other air traffic or to persons and property on the surface.

(b) *"No person may operate an unmanned free balloon below 60,000 feet standard pressure altitude between sunset and sunrise (as corrected to the altitude of operation) unless the balloon and its attachments and payload, whether or not they become separated during the operation, are equipped with lights that are visible for at least 5 miles and have a flash frequency of at least 40, and not more than 100, cycles per minute."*

(c) *"No person may operate an unmanned free balloon that is equipped with a trailing antenna that requires an impact force of more than 50 pounds to break it at any point, unless the antenna has colored pennants or streamers that are attached at not more than 50 foot intervals and that are visible for at least one mile."*

(d) *"No person may operate between sunrise and sunset an unmanned free balloon that is equipped with a suspension device (other than a highly conspicuously colored open parachute) more than 50 feet along, unless the suspension device is colored in alternate bands of high conspicuity colors or has colored pennants or streamers attached which are visible for at least one mile."*

§101.37 Notice requirements.

(a) *"Prelaunch notice : Except as provided in paragraph (b) of this section, no person may operate an unmanned free balloon unless, within 6 to 24 hours before beginning the operation, he gives the following information to the FAA ATC facility that is nearest to the place of intended operation:"*

(1) *"The balloon identification."*

(2) *"The estimated date and time of launching, amended as necessary to remain within plus or minus 30 minutes."*

(3) *"The location of the launching site."*

(4) *"The cruising altitude."*

(5) *"The forecast trajectory and estimated time to cruising altitude or 60,000 feet standard pressure altitude, whichever is lower."*

(6) *"The length and diameter of the balloon, length of the suspension device, weight of the payload, and length of the trailing antenna."*

(7) *"The duration of flight."*

(8) *"The forecast time and location of impact with the surface of the earth."*

(b) *"For solar or cosmic disturbance investigations involving a critical time element, the information in paragraph (a) of this section shall be given within 30 minutes to 24 hours before beginning the operation."*

(c) *"Cancellation notice : If the operation is canceled, the person who intended to conduct the operation shall immediately notify the nearest FAA ATC facility."*

(d) *"Launch notice : Each person operating an unmanned free balloon shall notify the nearest FAA or military ATC facility of the launch time immediately after the balloon is launched."*

§101.39 Balloon position reports.

(a) *"Each person operating an unmanned free balloon shall:"*

(1) *"Unless ATC requires otherwise, monitor the course of the balloon and record its position at least every two hours; and"*

(2) *"Forward any balloon position reports requested by ATC."*

(b) *"One hour before beginning descent, each person operating an unmanned free balloon shall forward to the nearest FAA ATC facility the following information regarding the balloon:"*

(1) *"The current geographical position."*

(2) *"The altitude."*

(3) *"The forecast time of penetration of 60,000 feet standard pressure altitude (if applicable)."*

(4) *"The forecast trajectory for the balance of the flight."*

(5) *"The forecast time and location of impact with the surface of the earth."*

(c) *"If a balloon position report is not recorded for any two-hour period of flight, the person operating an unmanned free balloon shall immediately notify the nearest FAA ATC facility. The notice shall include the last recorded position and any revision of the forecast trajectory. The nearest FAA ATC facility shall be notified immediately when tracking of the balloon is re-established."*

(d) *"Each person operating an unmanned free balloon shall notify the nearest FAA ATC facility when the operation is ended."*

5 Socioeconomic environment - Project Costs

Socioeconomic environment

Stratospheric balloons exist for more than a century, as mentioned in Section 1. However, there has always been a great mistrust in air transports even though statistics show that this way of transportation is much safer in comparison to road transports, such as cars or motorbikes.

Nevertheless, the biggest peak weather balloons are undergoing happens as of today. Not only much greater altitudes in the upper limit of the stratosphere are reached, but also a new area above near space is being explored. This decisive point throughout their lifespan encompasses a lot of entrepreneurs and innovators that dare to give them uses still not tried to this day. New technologies such as the upcoming ones are capable of fulfilling these aims with a significant amount of improvements within the field: [42]

- **Station-keeping**. Balloons can wait in up-there built platforms so long as a mere possibility of drifting away because of strong winds exists.
- **Point-to-point flight**: Greatly more defined and precise flight paths over near ground and through atmospheric layers - not so dependant on wind currents.
- **Routine long-duration flight**: Up to weekly and monthly flights' duration and improvement of performance capabilities.
- **Costs decrease**: Much lower costs in experimental fields and new commercial and tourist areas towards affordable stratospheric flights within a few years.
- **Advanced balloon manufacturing**: Artificial intelligence and more sophisticated manufactured materials and methods are increasing production rates to a huge worldwide extent.

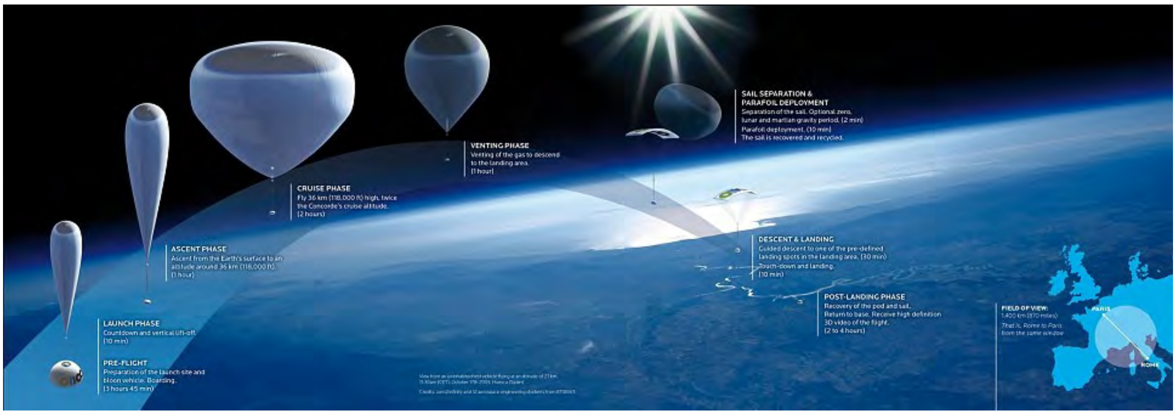

Figure 37: Phases of an idyllic stratospheric voyage [43]

Each of these capabilities are completely revolutionary in this still unexplored field that today gives grounds to expect a lot more advanced developments yet to come in one or two decades. Even more and more, higher initial investments of the order of millions of euros are invested by risk takers and early adopters. These companies play decisive roles when it comes to scouting regarding themes, such as better monitoring of the dense atmospheric layers to improve weather data collections, the new edge of space tourism, high-altitude experimental techniques to afterwards intend to orbit or surveillance applications to oversee air traffic in a greatly improved manner.

A few examples of these companies are “Near Space Corporation - NSC” [44] or “Arizona World View company”, within the private American near-space exploratory and technological “W.V. Enterprises Incorporation”. [45]. Their projects encourage the innovation, the exploration, the determination and the commitment needed to reach the already cited human dreams.

Figure 38: Balloon launch from Arizona World View company [45]

Project costs - Budget

The budget of a project encompasses all its costs, subdivided by definition in two types: direct and indirect. However, as this project comprehends and involves many people in it, too many costs would have to be taken into account for a complete accurate monetary analysis. Therefore, only the costs included within this thesis will be considered, and not a general financial study of the overall project will be developed.

Direct costs

Direct costs are expenses assigned in a straightforward way to a specific product, service, activity, department or project under development. Within this project in question, direct costs are summarized in labour and software. Most of these expenses are variable, but this may not always be the case. In fact, the salary of a supervisor who has monitored the progression of a student's bachelor thesis is a direct fixed cost.

An estimation of these direct variable and fixed costs are recorded hereunder in Tables 10 and 11.

Worker	**Price [€/h]**	**Time [h]**	**Total [€]**
Student	6.5	550	3575
Supervisor	28	100	2800

Table 10: Labour costs

On the one hand, student labour costs are calculated based on the average salary of a recently graduated engineering intern, which is about 750 or 800 € for a part-time job of 6 hours per day. In addition, more than the supposed 360 hours of work for a Bachelor's thesis (12 ECTS) are taken into consideration as an approximation of the spent hours in the project was performed - See Appendix C. On the other hand, the reference prices for a Doctor within the uc3m are contained in Appendix D. An average salary between maximum and minimum amounts per hour that the Professor costs the University has been considered.

Software	**License**	**Version**	**Total [€]**
Matlab	Student	R2018a	70
Windows	10	Home	135

Table 11: Software costs

It is important to mention that "Matlab R2018a" and "Windows 10" have been specifically downloaded for this code development and implementation, as "Matlab R2017b" and "Windows 7" were the versions previously used in this computer. In fact, software licenses' prices of Matlab and Windows are cheaper than single-user versions because of an academic and educational teaching usage.

Hence, the total sum of the direct variable and fixed costs is:

Item	**Price [€]**
Labour	6375
Software	205
Total	6580

Table 12: Total direct costs

Indirect costs

Indirect costs are expenses that cannot be straight related to the product, service, activity, department or project in development in question. The indirect expenses associated to this thesis are the laptop used for calculations - its depreciation, electricity and Internet connectivity.

The laptop used to perform all analyses and comparisons within this thesis has been a “Surface Pro 3”, purchased for a selling price of 1200€ 2 years ago. As this computer has not only been employed for this work, the depreciation of the computer is taken as an indirect cost too, just as explained above. Assuming a linear depreciation through the whole devaluation period and 10 years of useful life (U L), an estimation of how much money this computer declines in value over time is computed in the following way:

$$Depreciation = \frac{Initial\ price\,[€]}{UL\,[years]} = \frac{1200\ [€]}{10\ years\ of\ UL} = 120\ €/_{year} \tag{32}$$

Therefore, a rough calculation regarding the time spent with the laptop within the project is estimated. A third of the total amount of time using the laptop since the beginning of the project resulted. As a consequence, the amortization cost during the whole project duration is:

$$Amortization = \frac{1}{3}\,120 = 40\ €/_{year} \tag{33}$$

Moreover, the rest of the aforementioned indirect costs of Internet connectivity and electricity are not particularly easy to measure. Thus, a 2% of the total direct costs is assumed as their broadly contribution.

Item	**Price [€]**
Amortization	40
Other	132
Total	172

Table 13: Total indirect costs

Finally, the budget this thesis has demanded is collected in the next Table 14:

Item	**Price [€]**
Direct costs	6850
Indirect cost	172
Total	7022

Table 14: Total costs

6 Entrepreneurial B.Sc. Final Thesis

6.1 The frame of reference

The "Entrepreneurial B.Sc. Final Thesis" - in Spanish "TFG Emprende" - aims to be an instrument for the students within Charles III University of Madrid - uc3m - to get involved inside the culture of entrepreneurship, innovation and new technologies. This idea is carried out as a competition among contestants.

Figure 39: TFG Emprende - uc3m [46]

Within this contest, multiple professionals from different sectors but all, in one way or another in contact with the entrepreneurial world, are brought to explain us in several workshops mainly the two following highlighted issues for undertaking: [46]

- **Block I: "Innovation & Competitive advantage"** includes:
  - Concrete exemplifications of innovative companies to expand futuristic insights for the projects in question.
  - In-depth lectures to have a competitive advantage and to be of difficult accessibility to competitors.
  - Explanations on the two head types of entrepreneurship that exist in the current market - IDE (broadening global opportunities) and SME (focused on local markets).

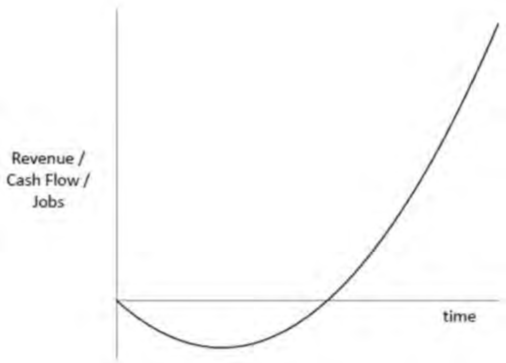

Figure 40: IDE Growth- Revenue, Cash Flow, Jobs over time [47]

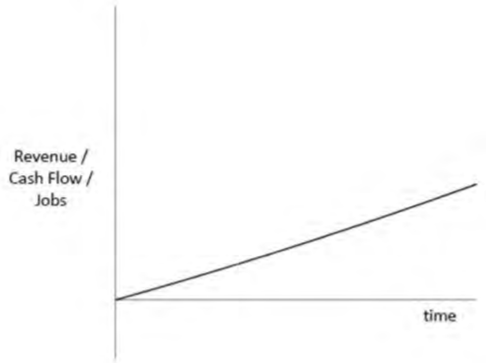

Figure 41: SME Growth - Revenue, Cash Flow, Jobs over time [47]

- **Block II: "Business"** covers:
  - Clear distinctions between a "start-up" (technology-based businesses such as IDE) and a "company" (traditional ventures with minor risks like SME).
  - List of the principal differentiations among a "business plan" and a "business model" and some diverse types of the last-mentioned model.

Business plan	Business model
Strategic document that focuses on: - The steps the company will take in the following years - Future goals that are intended to be achieved in the next business level	- Prior tool to the business plan - Dynamic allowing modifications over time or validations of previous initial hypotheses - Implemented strategies to give an added value to the company and differentiate the product or service from the competition

Figure 42: Business plan and model [47]

6.2 The undertaking idea

"Minimum Viable Product" - MVP - is the idea that validates if a proposed new business could become a start-up. The chosen MVP for this project is as follows: *"Undertaking that provides full network coverage through weather balloons to hospitals in developing countries so that a better organization and primary health care can be offered to many more people"*.

Plenty of benefits are addressed within this balloon project, including that many more people could be assisted at the same time within the same hospital and that registrations of each patient's illnesses could be much better diagnosed as reliable medical health records and much faster communication between nearby hospitals could be achieved.

Non-Governmental Organizations - NGOs - would be the main clients and users. This MVP's frequency of use is estimated to be applied on a daily basis. A survey performed among doctors and volunteers revealed that their opinions are very much in favor of these stratospheric balloons because of their great support and help, as well as their huge range capacity and autonomy in the air for a such low price.

Nevertheless, the view of using unmanned high-altitude balloons not only for collecting atmospheric data but also as a commercial application emerged in many entrepreneurs' minds that led to similar spectacular ideas.

There already exist companies such as the Spanish "Zero2Infinity" (02∞) or the American "Google X" or also named "Google [x]" that seek prototypes based on stratospheric balloons to improve human lives or progress in a technological and scientific field. Here are a few examples:

- **Project Bloon - from 02∞** - offers customers the possibility of experiencing what is like above 99.5% of the atmosphere. The day trip of a life time consists on seating comfortably in a pleasant environment, where an altitude up to 36 kilometres is reached to not only enjoy a spectacular view of our planet from the heights but also to learn a little bit more about Earth in a unique way. [48].
- **Bloostar - from 02∞** - is the given name to a "rockoon" (from 'rocket' and 'balloon'), which is sent into space to environmentally friendly put satellites into precise orbits. The balloon lifts the rocket through the densest parts of the atmosphere where gravity is more difficult to fight. At much greater altitudes, the rocket ignites once almost-vacuum conditions are reached, where barely no drag exists and rockets work at full efficiency. [48].

Figure 43: Bloon's capsule [48]

Figure 44: Bloostar's working principle [48]

- **Project Loon - from Google [x]** - delivers internet not only to rural areas away from cities where computer networks barely connects, but also to regions with an existent increased need, which might, for instance, be the case when cataclysms such as earthquakes or floods occur. [49].

Figure 45: Google X's wifi for the world [49]

The record of 190 days is what today a balloon holds floating in the stratosphere as maximum. That is about more than 6 months grabbing data from the Near

Space for future analyses, or more than 6 months capturing images and emitting and receiving radio signals in rescue missions, or more than 6 months providing a 24h surveillance system so that neither ships nor planes get lost on intercontinental trips. There are a huge amount of applications these objects of study could provide. Despite this, nothing is without uncertainty at the beginning.

"Remember to look up at the stars and not down at your feet. Try to make sense of what you see and wonder about what makes the universe exist. Be curious."
Stephen Hawking

6.3 Innovation and Business Model Canvasses

The Innovation Canvas

The Innovation Canvas basically serves to settle the ideas that explain how an entrepreneurial project could be carried out or also to improve already existing products, processes or services. Within *Block I: "Innovation & Competitive advantage"*, this tool is comprised of the four main zones: innovative object, impact, uncertainty and sustainable competitive advantage. [50]. The schematic outline proceeds below:

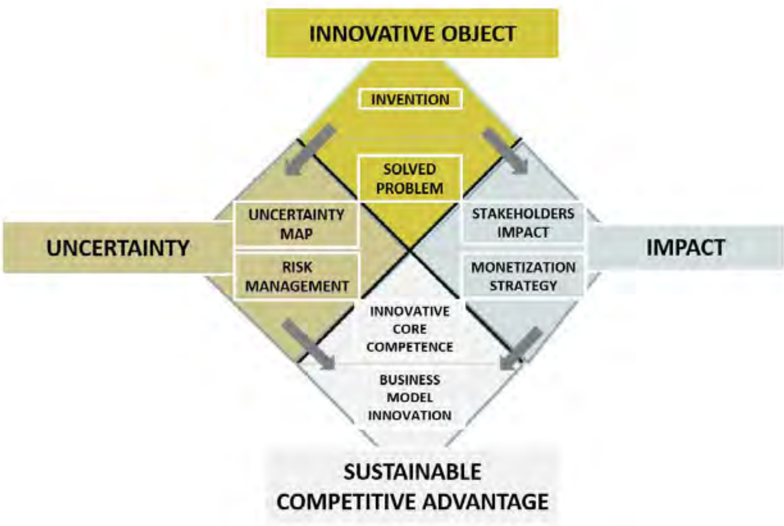

Figure 46: Innovation Pivot Framework

The part that plays the biggest role in The Innovation Canvas is "Uncertainty". It is generally true that "the greater the uncertainty, the greater the challenge". Hereafter one of the most disruptive today-existing projects in the global market.

"So what if you could type directly from your brain?"
Facebook Inc.

It is important to highlight that inside the "uncertainty map" section, the evolution of the project lead to perform a so-called "PESTEL" (See Fig.47). This type of analyses give a more closely insight of the environment in question, evaluate and monitor the level of disruption regarding many innovative parameters: P - Political, E - Economic, S - Social, T - Technological, E - Environmental and L - Legal.

Figure 47: P E S T E L [47]

The Business Model Canvas

The Business Model Canvas captures the logic any firm follow or could follow to achieve revenues. Inside the mentioned above *Block II: "Business"*, this model divides itself into 9 basic modules that cover the four main areas of a business: customers, offer, infrastructures and economic viability.

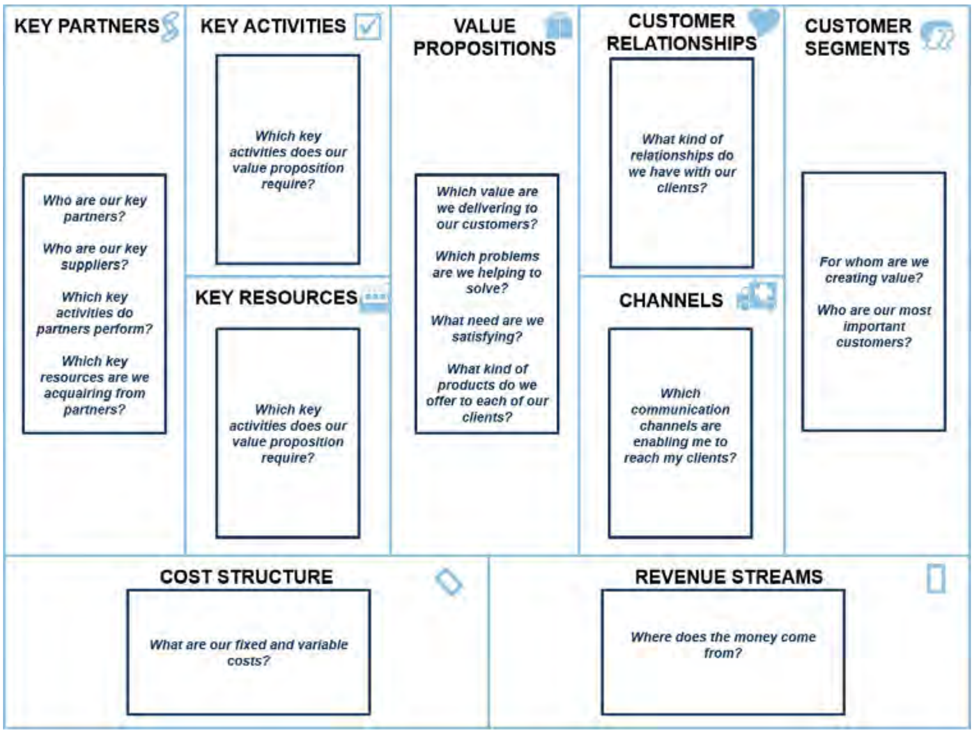

Figure 48: Business Framework [51]

Innovation, development, research, pro-activity or motivation are skills difficult to acquire and develop within challenges of such scale. However, as Eleanor Roosevelt - a social activist, the first lady and wife of US President Roosevelt - said:

"The future belongs to those who believe in the beauty of their dreams"

7 Conclusions and further considerations

7.1 Conclusions

The main objective of this project was the development of a high-altitude ballooning flight path predictor and its subsequent comparison with already existing softwares, such as HABHUB or ASTRA. To meet this goal, several steps have been entailed to achieve consistent final results.

The first block encompassed the understanding and study of the contents. On the one hand, a comprehensive analysis of the ISA model to see how pressure changes with altitude and a complete research of the different wind data within these Earth's layers have been covered. On the other hand, not only the non-elastic and the elastic Mooney-Rivlin and Gent-Gent models have been thoroughly explained to later decide whether elasticity was important or not within this project, but also the dynamics an stratospheric balloon followed in its trajectory.

The second block has mostly been focused on the implementation part. To begin with, a MATLAB code has been developed to show the evolution of certain important parameters with altitude to see whether elastic effects should have been considered. Result showed that because of the range of altitudes in which this experiment was going to take place, balloon envelope's elasticity was not needed to be taken into consideration as the membrane pressure difference between interior and exterior environments is much smaller compared to the existing ambient pressure. Afterwards, this same MATLAB code included the equations of motion of a stratospheric balloon to develop a proper interpolation model that predicts HAB flight paths.

Lastly, comparisons were essential to prove the validity of this new model. The "HABHUB Balloon Tracker" and this "MATLAB predictor" displayed pretty similar trajectories although slight differences were noted. It is worth emphasizing that only 37 wind data files where used inside this self-developed interpolation model. As these data is difficult to be correctly stored on their specific layers, not all the existing wind information has been considered in these MATLAB scripts. In addition, it must be borne in mind, that a real monitoring balloon evolution and its previous forecast have been compared, and not two predictors that are much prone to provide more alike behaviours. Even so, comparable similarities in flight paths and balloons' bursting altitudes have been accomplished and discussed.

To conclude, a possible fusion between the three HAB predictors could even be suggested to create an extremely precise and accurate software for not only professional, but also social and educational purposes.

7.2 Further considerations

As aforementioned in Section 1.3, many experiments and people are involved within this project and this thesis contributes only to a small part within it as a whole. Real data collection once the balloon is launched or the balloon's decent phase implementation could be some of the further evaluations that may be possibly examined in a near future.

Even though obtained outcomes are promising, there are still too many studies to learn, experiments to test and prove and plenty information to understand within this field. Nevertheless, a still not completely explored era concerning stratospheric balloons seems to be very much pointing towards a greatly exciting future.

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Appendix A 1600g Meteorological Balloon Data

PAWAN
433/2 Pune Nasik Road,
Kasarwadi, Nasik Phata,
Pune - 411034, India
T + 91-20-27125019
F + 91-20-27125622
info@pawanexport.com
www.pawanexport.com

Technical Specification for 1600g Meteorological Balloon

SPECIFICATION	CPR-1600
Weight, gm	1600
Payload, gm	1100
Recommend Free lift, gm	1310
Nozzle lift, gm	2310
Gross lift, gm	3910
Diameter at release, m	1.94
Rate of ascent, m/min	325
Diameter at burst, cm	950
Bursting altitude, km	34
Neck diameter, cm	8.5
Neck length	20-22
Colour	Uncolored/White

Note: Small or Large Neck Diameter does not affect Balloon Performance

Diameter at release is for recommended free lift and above mentioned payload. Should free lift or payload weight change, the diameter at release will consequently change.

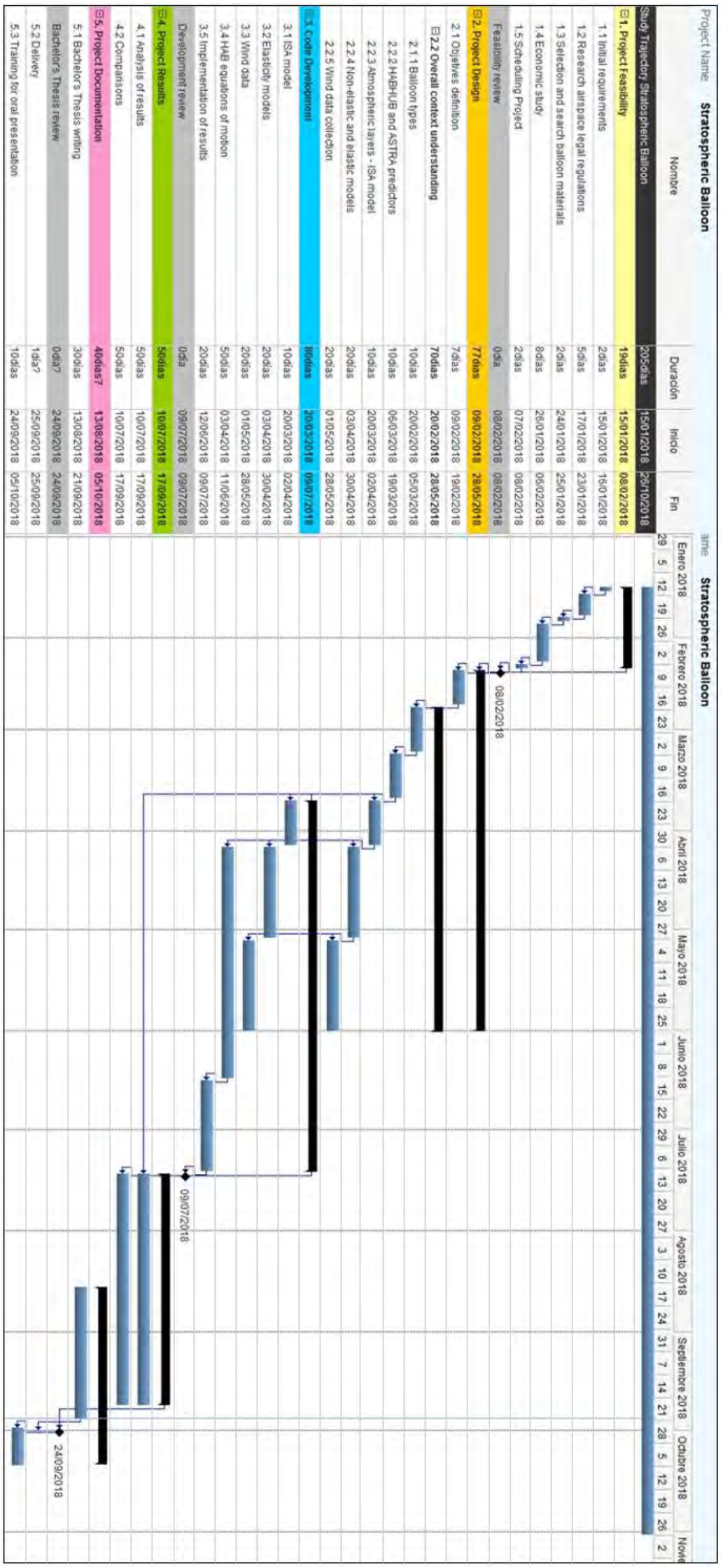
Appendix B MATLAB scripts

This MATLAB code is composed of a main script denoted as *"Equations of motion.m"* and the most two important auxiliary functions executed by calling *"elasticity.m"* and *"interpolate nomads.m"*.

The main cypher encloses all graphs and supporting functions. These two last functions are used to calculate non-elastic and elastic models and the self-developed trajectory predictor, respectively.

These three scripts are uploaded to an online webpage called "Dropbox". For further information, enter:
`https://www.dropbox.com/home/High-altitude%20Trajectory%20Predictor`

Appendix C Thesis Planning



Appendix D Contracting labour costs - uc3m

COSTE MENSUAL DE CONTRATACIÓN LABORAL*, SEGÚN TABLAS PARA 2016

	Bachiller / FP2		Titulado Medio		Titulado Superior				Titulado Doctor			
					MÍNIMO		*MÁXIMO*		*MÍNIMO*		*MÁXIMO*	
JORNADA	*Salario bruto*	**Coste proyecto**	*Salario bruto*	**Coste proyecto**	*Salario bruto*	**Coste proyecto**	*Salario bruto*	**Coste proyecto**	*Salario bruto*	**Coste proyecto**	*Salario bruto*	**Coste proyecto**
17,5H	*910,00*	**1236,24**	*1056,35*	**1435,06**	*738,67*	**1003,49**	*1265,46*	**1719,13**	*861,12*	**1169,84**	*1593,04*	**2164,16**
22,5H	*1170,00*	**1589,45**	*1358,17*	**1845,08**	*949,72*	**1290,20**	*1627,02*	**2210,32**	*1107,16*	**1504,09**	*2048,20*	**2782,49**
27,5H	*1430,00*	**1942,67**	*1659,98*	**2255,09**	*1160,77*	**1576,91**	*1988,58*	**2701,50**	*1353,20*	**1838,33**	*2503,35*	**3400,82**
32,5H	*1689,99*	**2295,87**	*1961,80*	**2665,11**	*1371,82*	**1863,63**	*2350,14*	**3192,68**	*1599,23*	**2172,57**	*2958,51*	**4019,16**
Completa (37,5H)	*1949,99*	**2649,08**	*2263,61*	**3075,13**	*1582,87*	**2150,34**	*2711,70*	**3683,86**	*1845,27*	**2506,81**	*3413,67*	**4637,49**
	Coste hora=	20,18	Coste hora=	23,43	Coste hora=	16,38	Coste hora=	28,07	Coste hora=	19,10	Coste hora=	35,33

*** Técnicos de apoyo a la investigación y personal investigador**. *Para contratos predoctorales consultar los costes al Servicio de Investigación*

***SALARIO ANUAL para cada jornada* = Salario Bruto x 12**
***COSTE PROYECTO anual* = Coste proyecto x 12**

Base máx cotización SS 2016: *3.642,00 €*